# UNIVERSIDAD AUTONOMA DE NUEVO LEON

## FACULTAD DE INGENIERIA MECANICA Y ELECTRICA

MEMORIA PARA EXAMEN PROFESIONAL
DE LA CARRERA DE INGENIERO MECANICO
ADMINISTRADOR

PRESENTA

CESAR ALEJANDRO GONZALEZ IBARRA

## C U R S O

PRUEBAS MECANICAS EN LOS MATERIALES
POR COMPUTADORA

EXPOSITOR: M.C. DANIEL RAMIREZ VILLARREAL

CD. UNIVERSITARIA MAYO DE 1996

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# CURSO -TESIS

# PRUEBAS MECÁNICAS EN LOS MATERIALES.

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4.- Máquinas, accesorios, aditamentos e instrumentos de medición. 23

Bibliografía

# 1.- Clasificación de los Materiales

**1.- Ferrosos:**

Aceros : Ordinarios
Aleados

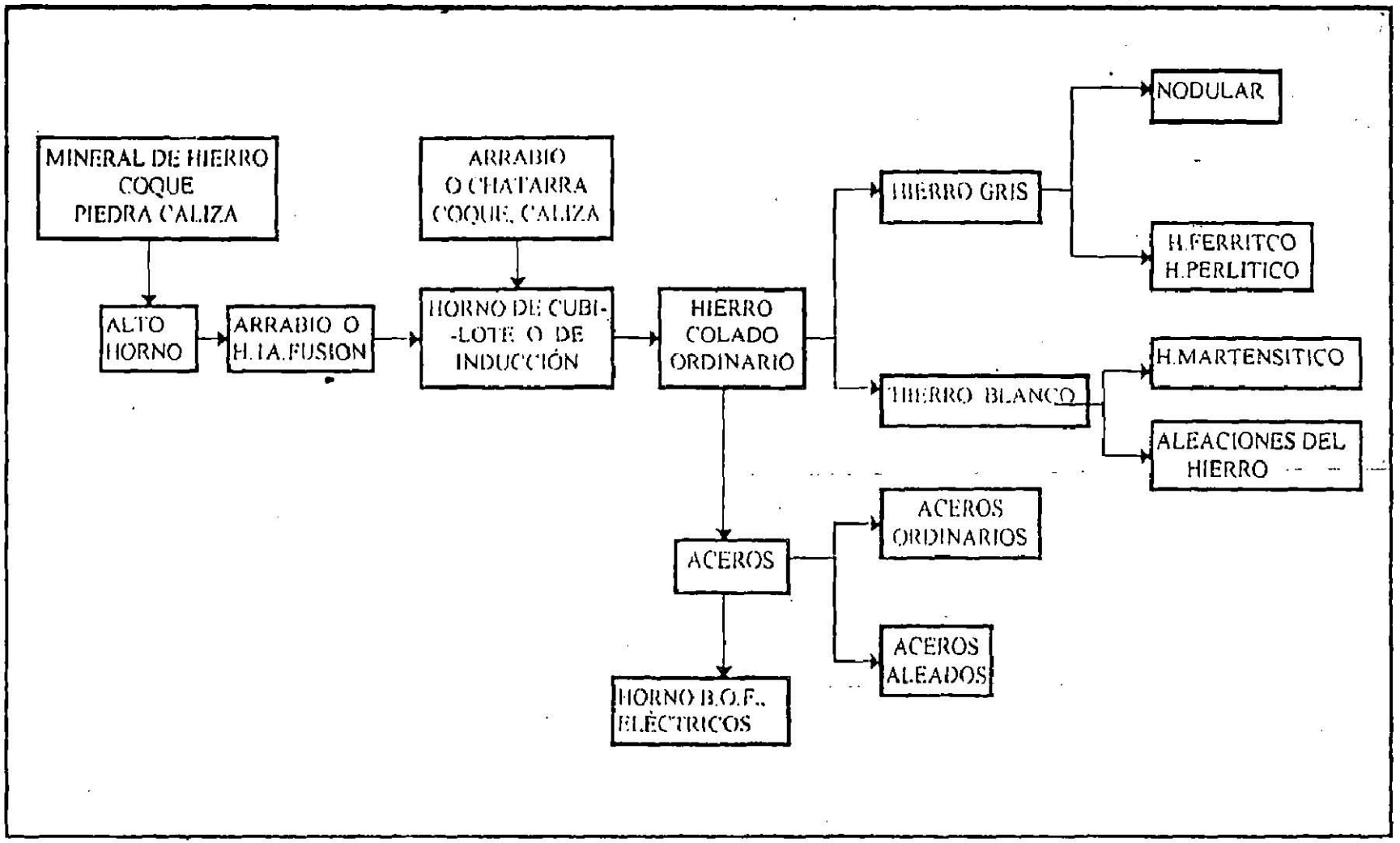
Fundiciones: Grises: Nodular
Ferrítico
Perlítico
Blancas: H. Martensíticos
Especiales Aleaciones

**2.- No-Ferrosos:** Cobre y sus Aleaciones
Aluminio y sus Aleaciones
Níquel, Cromo, Estaño, etc.

**3.- Orgánicos:** Madera
Polímeros
Elastómeros

**4.- Inorgánicos:** Fibras Compuestas
Cerámicos
Vidrios
Minerales

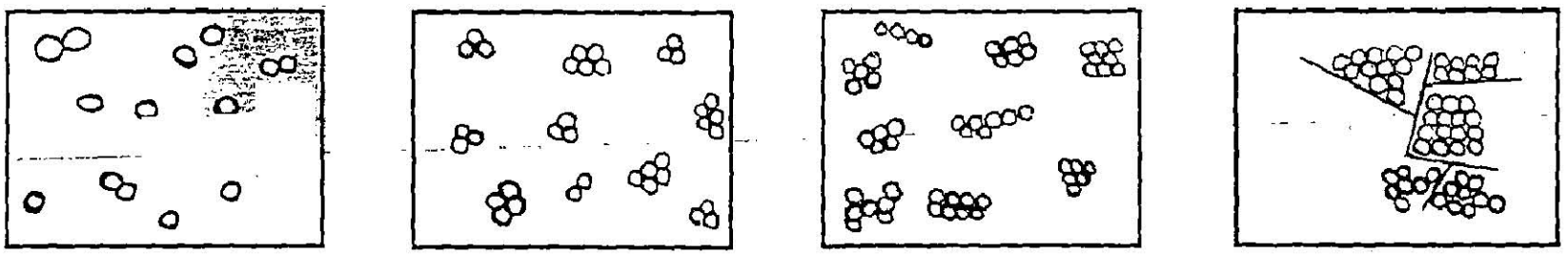
# DIAGRAMA DE OBTENCIÓN DEL HIERRO Y EL ACERO



# MECANISMOS DE CRISTALIZACIÓN EN LOS METALES

ES EL PROCESO DE TRANSFORMACIÓN DE UN ESTADO LIQUIDO A UNO SÓLIDO DESARROLLÁNDOSE LOS CRISTALES EN FORMA ORDENADA.

TEMP. ALTA ——————————————————————→ TEMP. NORMAL



FORMACIÓN DE NÚCLEOS DE ÁTOMOS

FORMACIÓN DE DENDRITAS

CRECIMIENTO DE CRISTALES

FORMACIÓN DE LIMITES DE GRANO

# 2.- Estructura de los Materiales

## METALES

**PARA METALES:** su estructura está compuesta por agrupamiento de átomos.

**Estados de la Materia en la Obtención de un Metal**

* Gaseosos
* Líquidos
* Sólidos

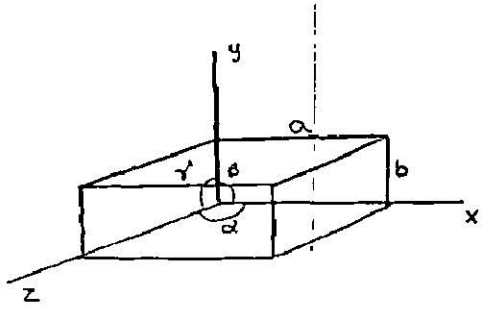
**Tipos de Enlaces**

* Iónico
* Metálico
* Covalente
* Vander-Walls
* Puente de Hidrógeno

**Red o estructura cristalina:** agrupación de átomos en forma ordenada denominadas celdillas espaciales.

**Características de la red:**

* Sus longitudes
* Sus ángulos



# LOS SIETE SISTEMAS CRISTALINOS

**1.-Monoclínico**
- a) Simple
- b) De extremos centrados

**2.- Triclínico**
- a) Simple

**3.- Hexagonal**
- a) Con extremos centrados

**4.- Romboédrico**
- a) Simple

**5.- Ortorrómbico**
- a) Simple
- b) Cuerpo centrado
- c) Extremos centrados
- d) Caras centradas

**6.- Tetragonal**
- a) Simple
- b) Cuerpo centrado

**7.- Cúbico**
- a) Simple
- b) Cuerpos centrados
- c) Caras centradas

**Los sistemas de cristalización más comúnes son:**

⇒ Cúbico*
⇒ Hexagonal*
⇒ Tetragonal
⇒ Ortorrómbico
⇒ Romboédrico

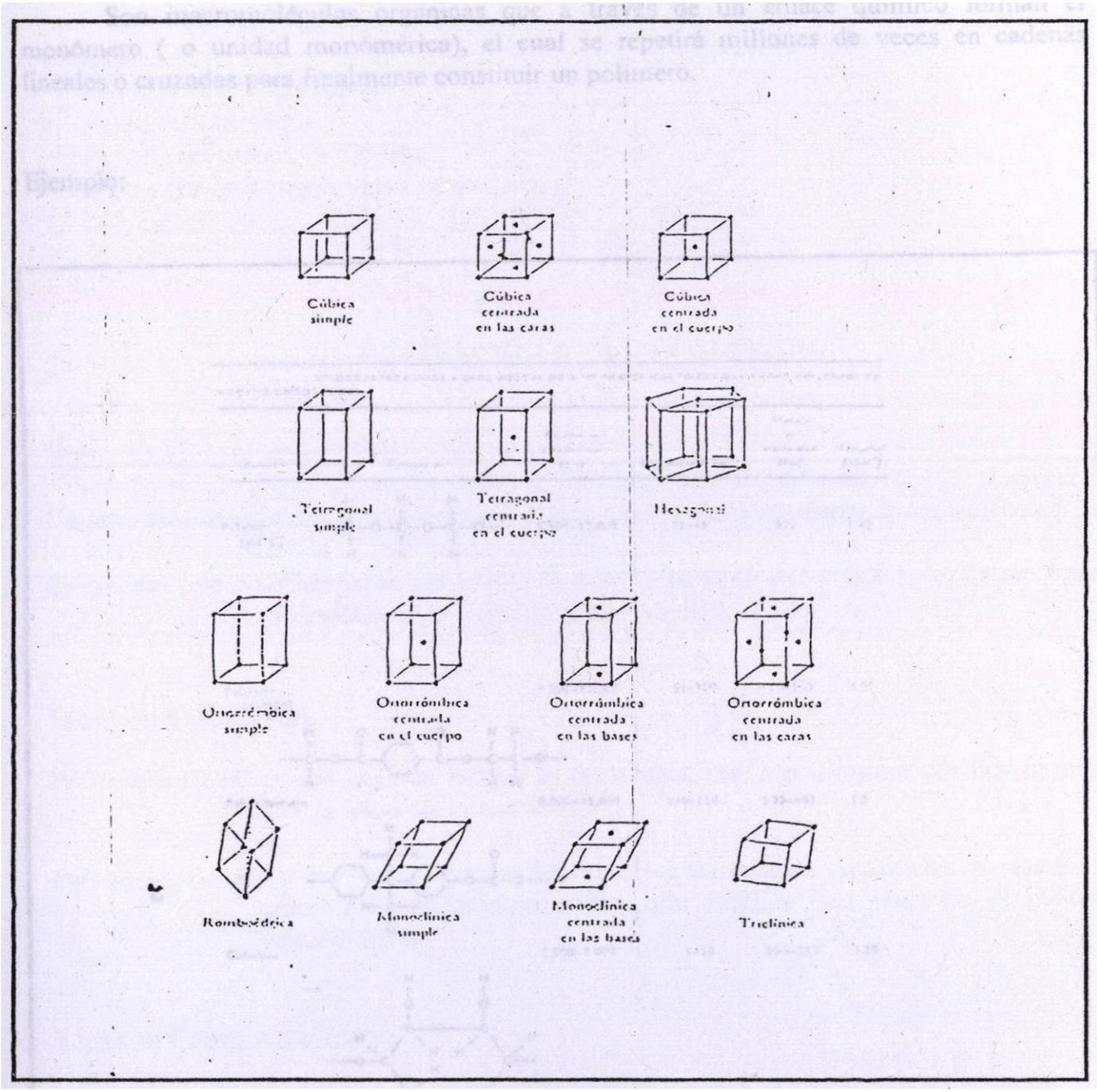
**Defectos o imperfecciones del cristal:**

⇒ Vacancias
⇒ Intersticios
⇒ Dislocaciones (Borde y Helicoidales)

Polimorfismo o Alotropía: es cuando el material se presenta en varias formas

* En metales

# REDES ESPACIALES O TIPOS DE ESTRUCTURAS CRISTALINAS



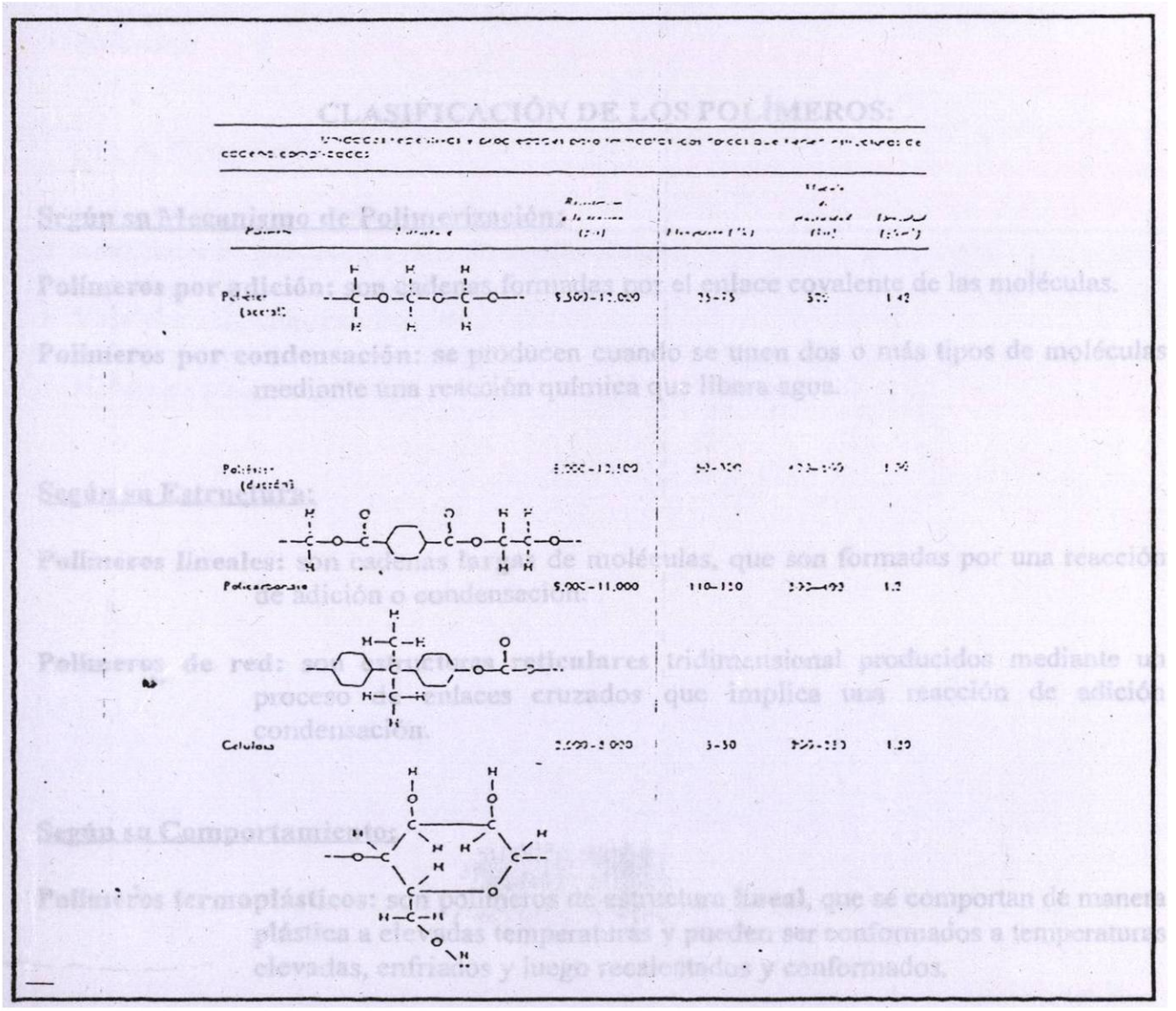

Los siete sistemas de estructura cristalina y las 14 redes de Bravals.

**NOVIEMBRE DE 1995**

# ESTRUCTURA DE LOS POLÍMEROS

Son macromoléculas orgánicas que a través de un enlace químico forman el monómero ( o unidad monomérica), el cual se repetirá millones de veces en cadenas lineales o cruzadas para finalmente constituir un polímero.

Ejemplo:



# POLÍMEROS

## CARACTERISTICAS GENERALES DE LOS POLÍMEROS:

* Ligeros
* Resistentes a la Corrosión
* Aislantes Eléctricos
* Baja Resistencia a la Tensión
* No usados en Temperaturas Altas
* Muy usual

## CLASIFICACIÓN DE LOS POLÍMEROS:

**Según su Mecanismo de Polimerización:**

**Polímeros por adición:** son cadenas formadas por el enlace covalente de las moléculas.

**Polímeros por condensación:** se producen cuando se unen dos o más tipos de moléculas mediante una reacción química que libera agua.

**Según su Estructura:**

**Polímeros lineales:** son cadenas **largas** de moléculas, que son formadas por una reacción de adición o condensación.

**Polímeros de red:** son estructuras **reticulares** tridimensional producidos mediante un proceso de enlaces cruzados que implica una reacción de adición condensación.

**Según su Comportamiento:**

**Polímeros termoplásticos:** son polímeros de estructura **lineal**, que se comportan de manera plástica a elevadas temperaturas y pueden ser conformados a temperaturas elevadas, enfriados y luego recalentados y conformados.

**Polímeros termoestables o termofijos:** son de red o estructura tridimensional **reticulado** por lo que se consideran rígidos y no se ablandan cuando se calientan se forman por reacción de condensación no se pueden reprocesar debido a que parte de las moléculas salen del material.

**Según su Grado de Polimerización:**

* Homopolímeros (un sólo material)
* Copolímeros (dos o más tipos)
* Oligopolímeros (pocos monomeros)
* Polímeros

**Según su Naturaleza:**

* Naturales (lino, seda,asbesto, celulosa)
* Artificiales o sintéticos (rayón, nitrato de celulosa)
* Según su origen
* Vegetales (algodón, celulosa, etc.)
* Animales (pelos)
* Minerales (asbestos, fibra de vidrio)

## POLÍMEROS INORGÁNICOS:

Son macromoléculas que se constituyen de cadenas que no contienen átomos de carbono.

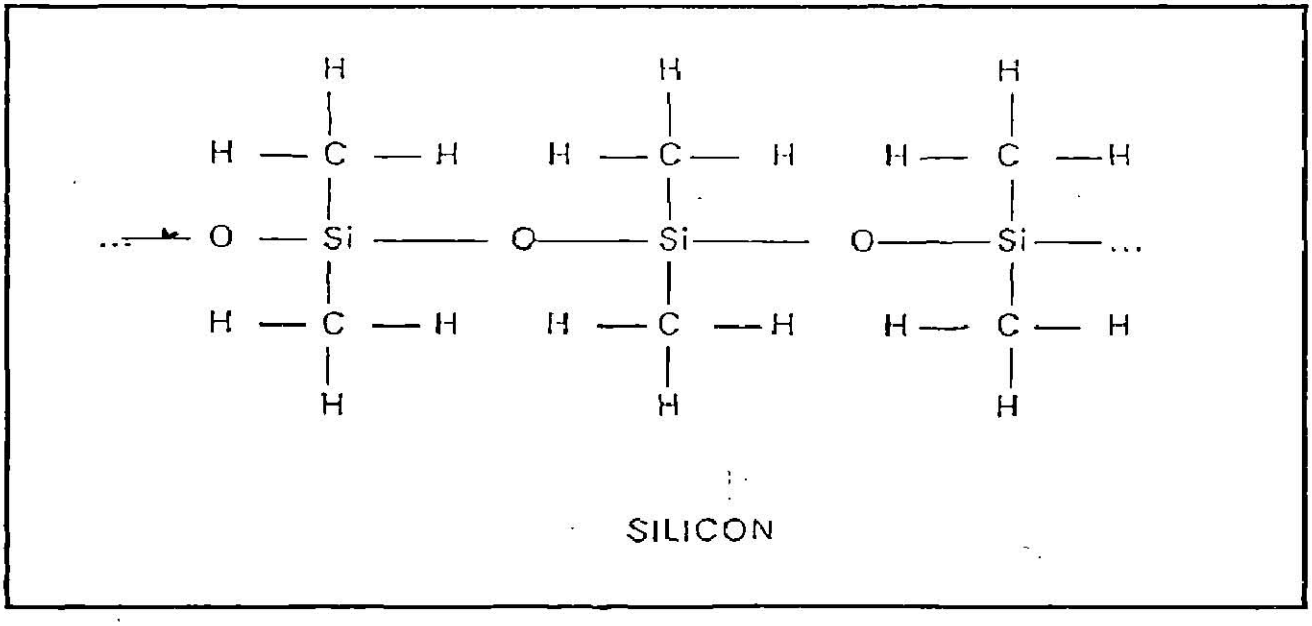
**Clasificación:**

**Naturales:** Asbestos
Fibras de carbono o de grafito obtenidas por extrusión.

**Artificiales:** Fibra de vidrio
Silicones

## ELASTOMEROS

**Elastómero (caucho o hules):** es una cadena polimérica que se encuentra enrrollada debido al arreglo cis de los enlaces, por lo que al aplicarse una fuerza se alarga al desenrrollarse las cadenas lineales, deslizandose unas sobre otras y provocando una combinación de deformación plástica y elástica. Tienen un comportamiento intermedio y la capacidad de deformarse elásticamente en alto grado sin cambiar de forma.



# 3.- Propiedades y Características Mecánicas en los Materiales

**OBJETIVO DE LA PRÁCTICA:** es el de conocer la manera de obtener las características y propiedades mecánicas básicas.

**TEORÍA:** basandonos en un ensaye estático de tensión y su gráfica de comportamiento esfuerzo vs deformación unitaria, obtendremos la siguientes características y propiedades mecánicas básicas en los materiales.

* Resistencia Mecánica
* Ductilidad
* Rígidez
* Resilencia
* Tenacidad
* Estandares de Probetas
* Velocidad del Ensayo
* Textura de Grano y Tipos de Fallas

**Resilencia Mecánica:** es la oposición que ofrece el material a traves de su fuerza interna (molecular) a la fuerza o carga aplicada.

**Esta se mide a traves de:**

**1.- Límite Proporcional ($\sigma_{L.P.}$):** es el mayor esfuerzo que un material es capaz de desarrollar sin perder la proporcionalidad entre esfuerzo y deformación, es decir, que representará el último punto en la pendiente de la gráfica, cumpliendo con la ley de hooke.

**2.- Límite Elástico ($\sigma_{L.P.}$):** es el mayor esfuerzo que un material es capaz de desarrollar sin que ocurra la deformación permanente al retirar el esfuerzo, la determinación de este límite elástico no es práctico y rara vez se realiza.

**3.- Resistencia a la Cedencia** ($\sigma_{Y.P.}$): es el esfuerzo al cual ocurre un aumento de deformación para cero incremento de esfuerzo.

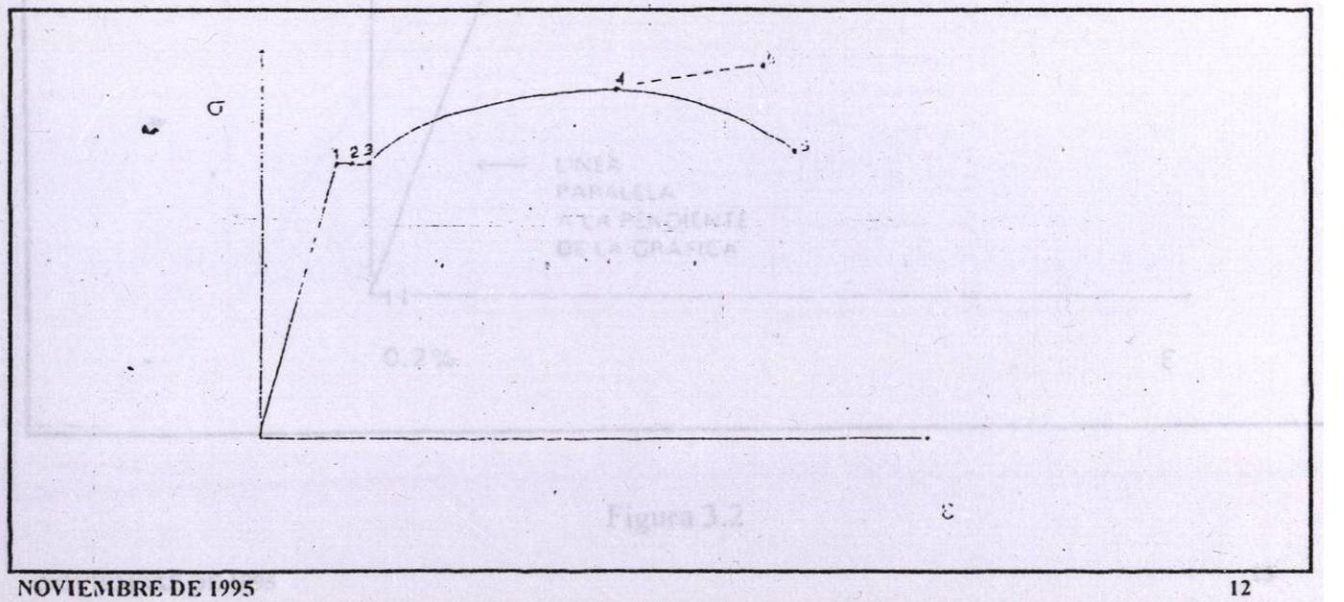
En este punto cede el material a los defectos de cristal (vacancias, intersticios y dislocaciones) por lo que provoca el desplazamiento molecular (deformación) sin oponerse a la fueza aplicada por lo que los incrementos de carga en la máquina de pruebas para algunos materiales.

**4.- Resistencia Máxima** ($\sigma_{max.}$): es el esfuerzo máximo que puede desarrollar el material debido a la carga aplicada, durante un ensaye hasta la roptura. (Se observa en la probeta el inicio de la reducción de área en materiales dúctiles).

**5.- Esfuerzo de Roptura** ($\sigma_{RUP.}$): es el esfuerzo nominal al ocurrir falla y se obtiene dividiendo la carga decreciente registrada en la carátula o pantalla de la máquina y el área inicial de la probeta.

**6.- Esfuerzo de Roptura Real o Verdadero** ($\sigma_{RUP.}$): es el esfuerzo nominal al ocurrir la falla y se obtiene dividiendo la carga entre el área real que disminuye conforme se aplica ésta.

Este esfuerzo es improbable sobre la sección crítica o de falla, ya que el laminado del metal causa el desarrollo de una compleja distribución de esfuerzos.



## OBTENCIÓN DEL PUNTO DE CEDENCIA:

Se define como el esfuerzo al cual ocurre una gran deformación sin incremento de carga o esfuerzo.

En algunos materiales este punto de cedencia no se presenta como en otros, que a traves de la oscilación de la aguja en la carátula de la lectura de carga o del canal en el display de carga, se puede detectar dicho punto en máquina universal.

El método para determinar el punto de cedencia se le conoce como método "offset" o "desplazamiento".

El método consiste en trazar una línea o recta paralela a la pendiente de la gráfica a partir de un valor de deformación unitaria de 0.001, 0.002, 0.003 in/in. Que representará 0.1%, 0.2%, 0.3% de deformación unitaria. El valor más usual es el 0.2% ver figura 3.2.

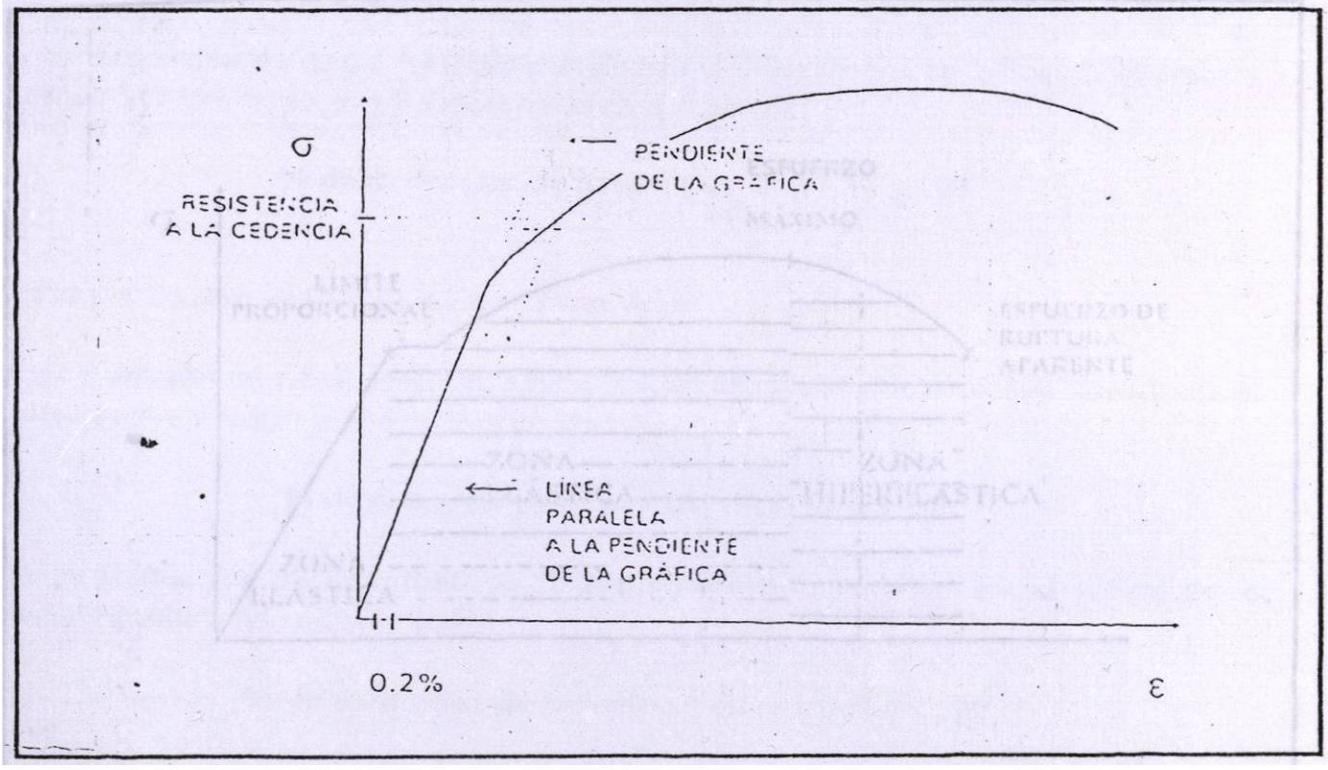



Figura 3.2

## ZONAS EN LA GRÁFICA:

**1.- Zona Elástica:** se considera desde el origen hasta el punto límite proporcional. Se emplea en el diseño de elementos de máquinas y estructuras,

**2.- Zona Plástica:** se considera desde el punto de cedencia hasta el punto de esfuerzo máximo.
Se emplea para darle forma al material por ejemplo los procesos de mecanizado (torneado, troquelado, doblado, extruido, etc.), laminados (en caliente y en frío). Esta zona se divide: en zona de cedencia y zona de endurecimiento por deformación.

**3.- Zona Hiperplástica:** se considera en algunos materiales desdes el punto de de esfuerzo máximo hasta el punto de roptura aparente.
Se emplea en el diseño de elementos de máquinas, productos y estructuras que deben absorber grandes cantidades de energía meánica (energía cinética o potencial).

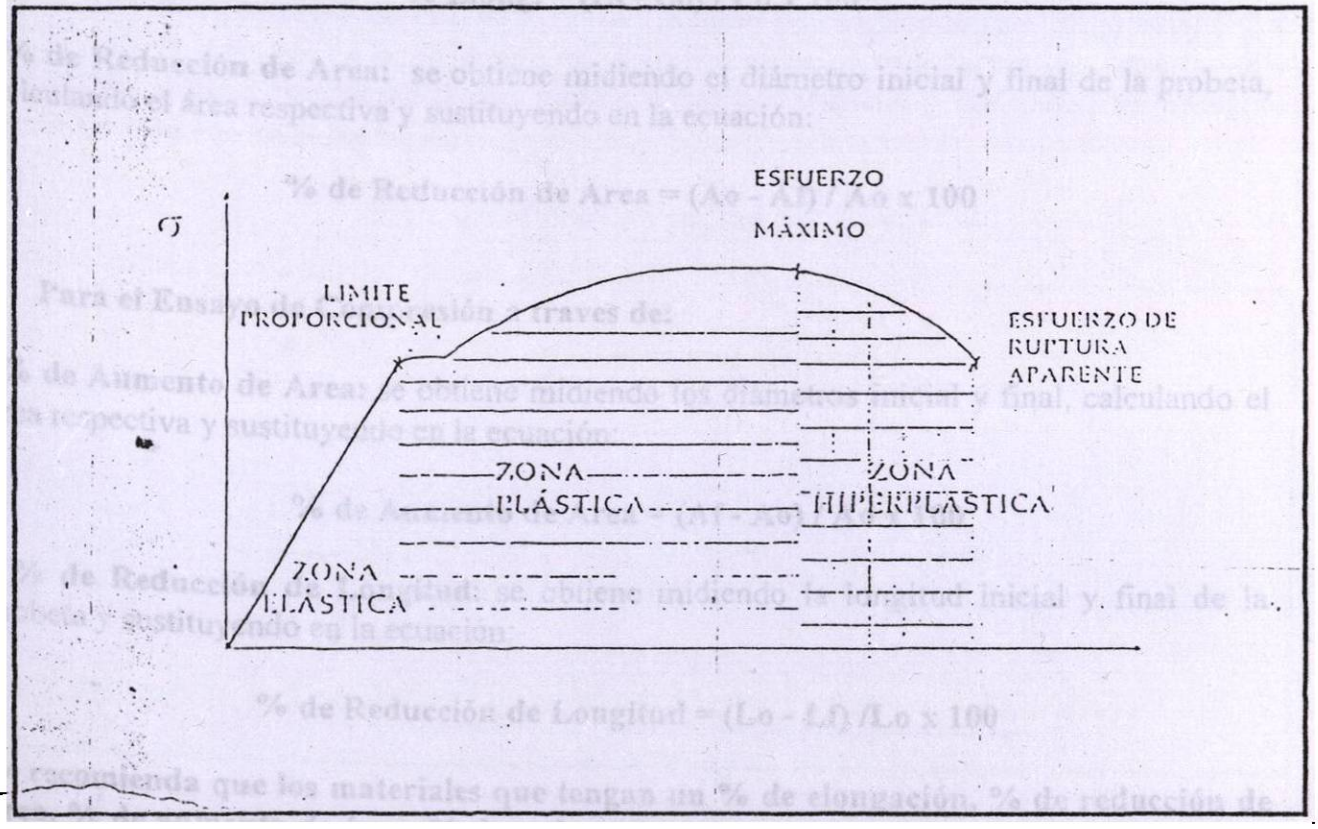



Figura 3.3

## DUCTILIDAD

Es la propiedad que tienen los materiales de deformarse en grande.

## FRAGILIDAD

Es la propiedad que tienen los materiales de no presentar deformación macroscópica.

**Estas propiedades son medidas:**

* **Para el Ensayo de Tensión a traves de:**

**-% de Elongación:** se obtiene midiendo la longitud inicial (Lo) y la final (Lf) de la probeta y luego sustituyendo en la ecuación:

$$\% \text{ Elong.} = (Lf - Lo) / Lo \times 100$$

**-% de Reducción de Area:** se obtiene midiendo el diámetro inicial y final de la probeta, calculando el área respectiva y sustituyendo en la ecuación:

$$\% \text{ de Reducción de Area} = (Ao - Af) / Ao \times 100$$

* **Para el Ensayo de Compresión a traves de:**

**-% de Aumento de Area:** se obtiene midiendo los diámetros inicial y final, calculando el área respectiva y sustituyendo en la ecuación:

$$\% \text{ de Aumento de Area} = (Af - Ao) / Ao \times 100$$

**- % de Reducción de Longitud:** se obtiene midiendo la longitud inicial y final de la probeta y sustituyendo en la ecuación:

$$\% \text{ de Reducción de Longitud} = (Lo - Lf) / Lo \times 100$$

**Se recomienda que los materiales que tengan un % de elongación, % de reducción de área, % de aumento de área, % de reducción de longitud, mayor de 5 %, para que se consideren dúctiles.**

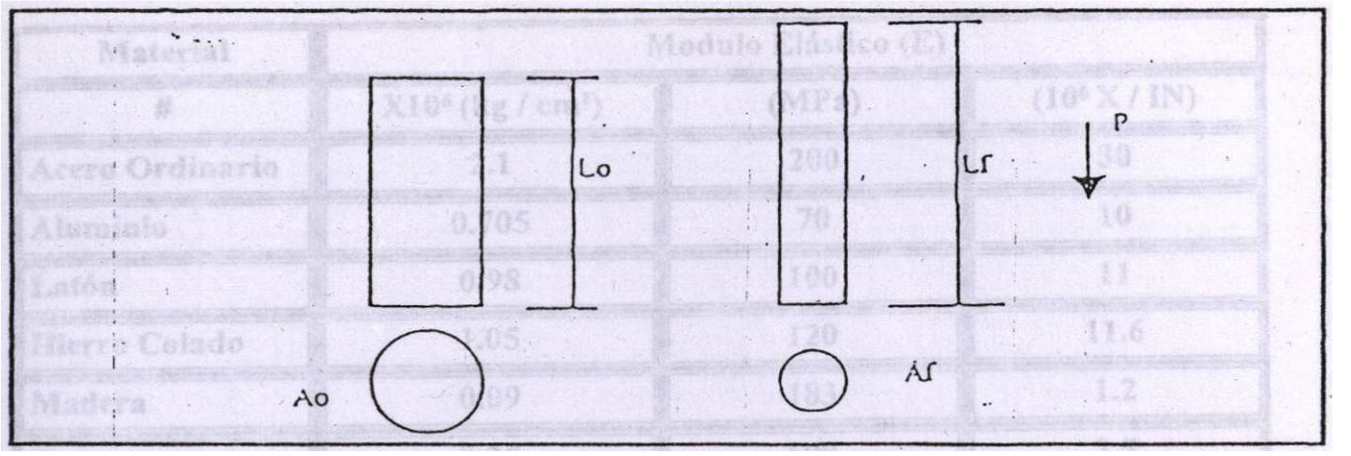



Figura 3.4

## RIGIDEZ:

Es el esfuerzo requerido para producir una deformación dada.

Se mide a traves de la obtención del modulo de elasticidad para carga axial (E) y representa la tangente de la pendiente en la gráfica esfuerzo vs deformación, este modulo se puede obtener considerando dos puntos sobre la pendiente y realizando un triángulo como se muestra en la figura 3.5

$$E = Tg\ \theta = \Delta\sigma/\Delta\varepsilon = (\sigma_2 - \sigma_1) / (\varepsilon_2 - \varepsilon_1)$$

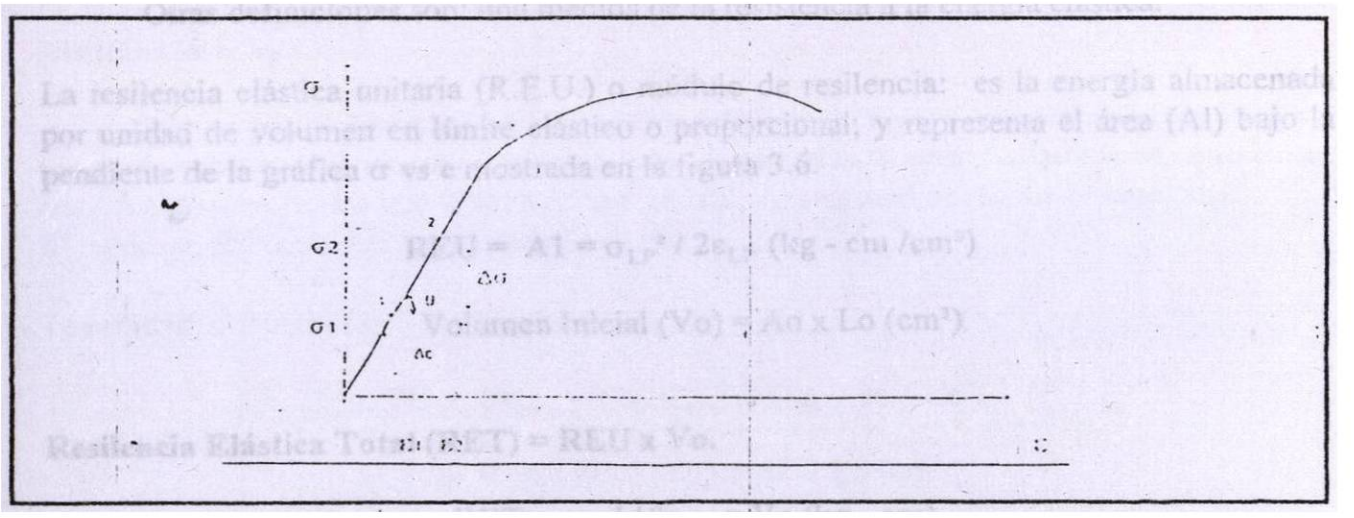



Figura 3.5

| Material | Modulo Elástico (E) | | |
|---|---|---|---|
| # | $X10^6$ (kg / cm²) | (MPa) | ($10^6$ X / IN) |
| Acero Ordinario | 2.1 | 200 | 30 |
| Aluminio | 0.705 | 70 | 10 |
| Latón | 0.98 | 100 | 11 |
| Hierro Colado | 1.05 | 120 | 11.6 |
| Madera | 0.09 | 183 | 1.2 |
| Concreto | 0.25 | 500 | 3.5 |
| Plástico | 0.56 | 116 | 0.8 |

Valores promedio de modulo de elasticidad de algunos materiales
Tabla 1.1

## RESILENCIA ELÁSTICA:

Es la propiedad que tienen los materiales de absorber energía hasta su límite proporcional o elástico (energía elástica).

Otras definiciones son: una medida de la resistencia a la energía elástica.

La resilencia elástica unitaria (R.E.U.) o módulo de resilencia: es la energía almacenada por unidad de volumen en límite elástico o proporcional; y representa el área (Al) bajo la pendiente de la gráfica $\sigma$ vs $\varepsilon$ mostrada en la figura 3.6.

$$\mathbf{REU = A1 = \sigma_{LP}^2 / 2\varepsilon_{LP}\ (kg - cm / cm^3)}$$

Volumen Inicial (Vo) = Ao x Lo ($cm^3$)

**Resilencia Elástica Total (RET) = REU x Vo.**

$$\mathbf{RET = \sigma_{LP}^2 / 2\varepsilon_{LP} \times Vo\ (kg - cm)}$$

L.P.: Límite proporcional.

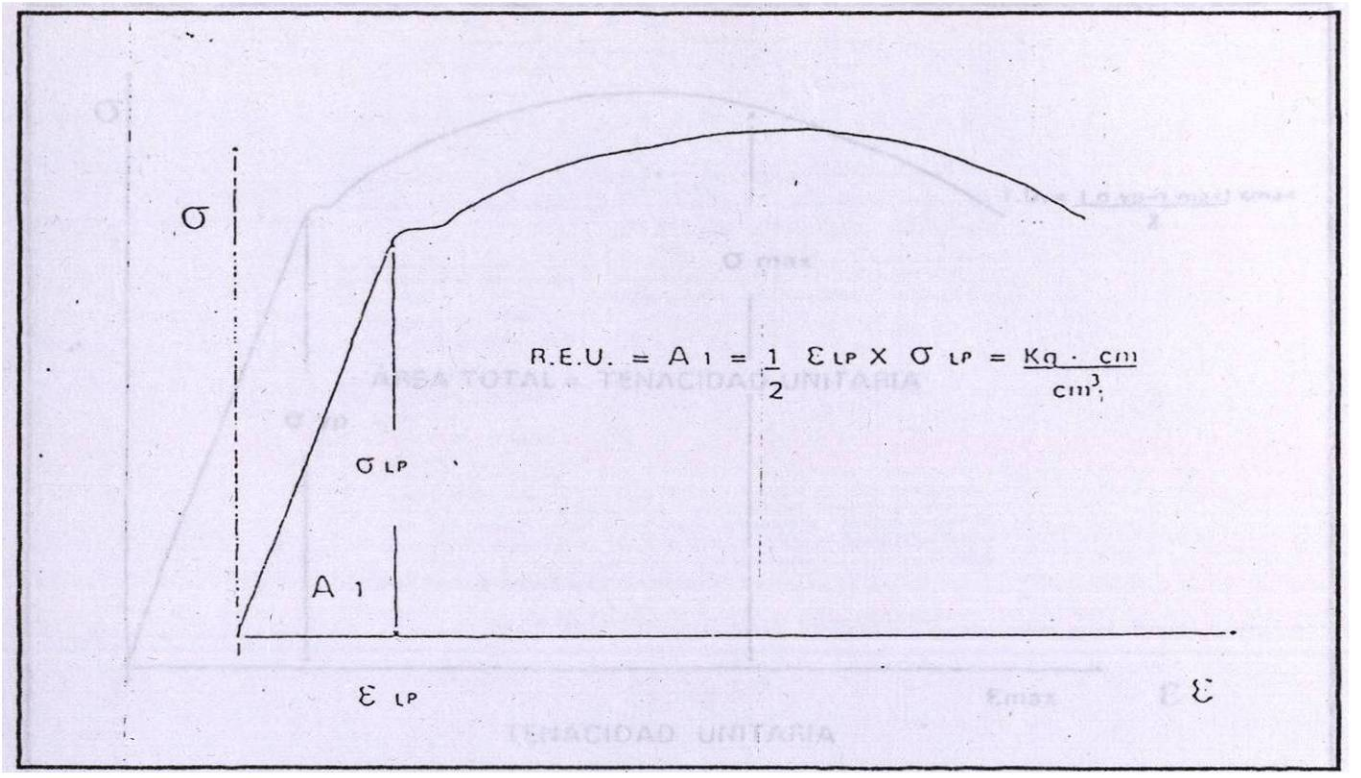



Figura 3.6

## TENACIDAD:

Es la propiedad que tienen los materiales de absorber energía hasta el punto de roptura (energía plástica).

Representa el área total bajo la gráfica esfuerzo-deformación, esta se puede medir a traves de seccionar el área en áreas regulares y sumarlas, o con el planímetro, que es un instrumento para determinar el área de una gráfica. Al seguir el contorno de la misma.
El valor así obtenido será la tenacidad unitaria.

**Tenacidad Unitaria (TU) = Area total**

$$TU = (\sigma_{max} - \sigma_{YP})\, \varepsilon_{max} / 2 \text{ (kg - cm / cm}^3\text{)}$$

Volumen Inicial (Vo) = Ao x Lo ($cm^3$)

**Tenacidad Total (TT) = TU x Vo (kg - cm)**

YP (Yield Point): Punto de cedencia.

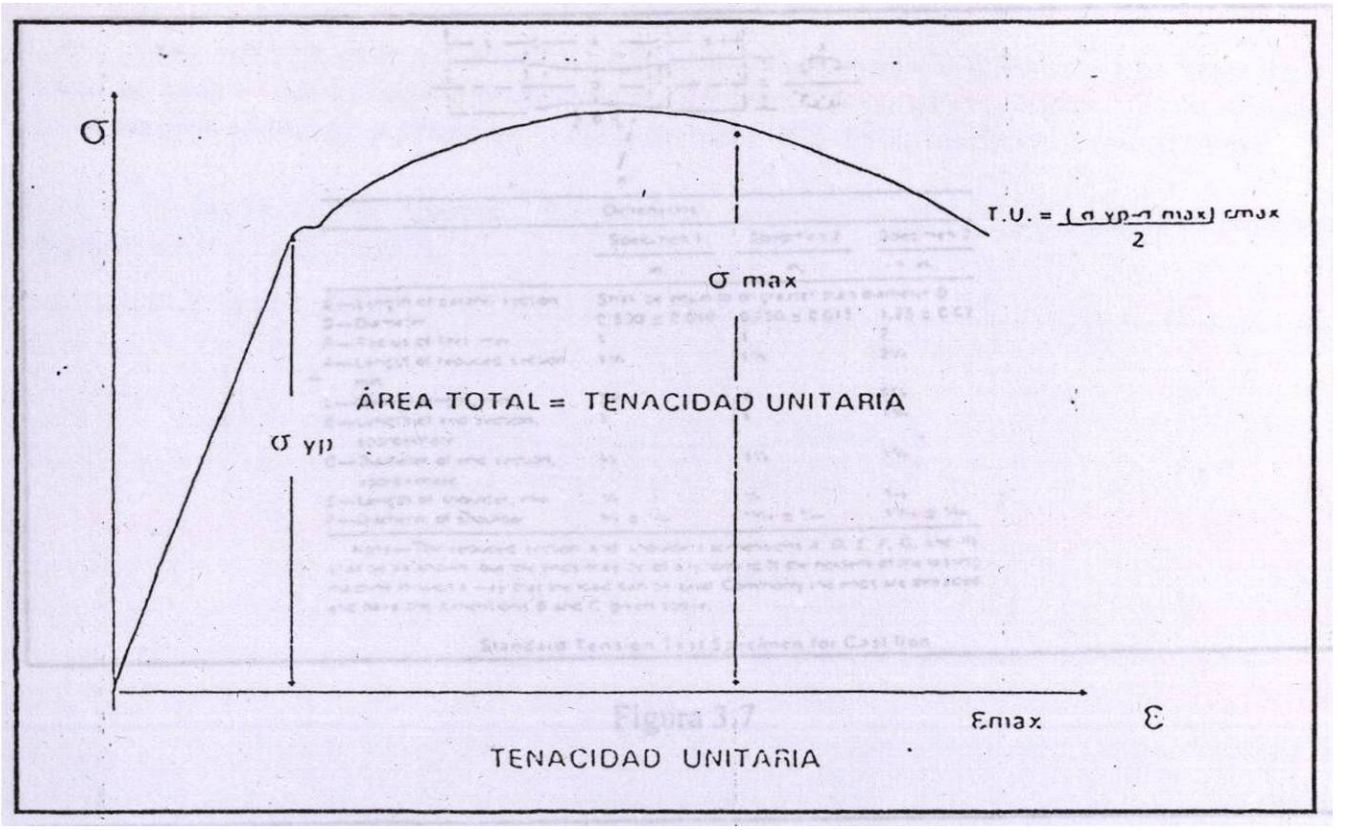



Figura 3.6a

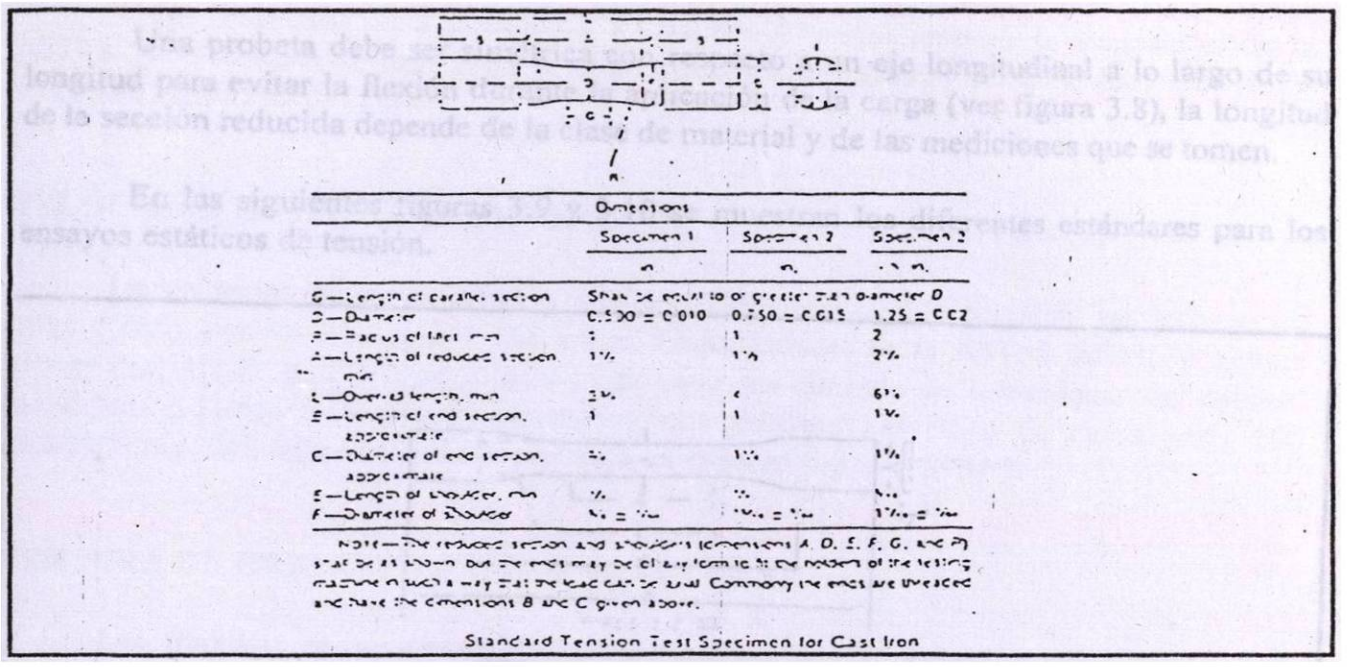
## ESTANDAR DE PROBETAS PARA TENSIÓN:

Las probetas para ensatos de tensión se realizan de diferentes formas la sección transversal del especimen puede ser redonda, rectangular o irregular según sea el caso.

Las formas dimensionales de la probeta depende de las asignaciones que estipule las normas referidas por las agencias de ensaye e inspección en los materiales y productos.

La porción del tramo recto es de sección menor que los extremos para provocar que la falla ocurra en una sección donde los esfuerzos no resulten afectados por los aditamentos de sujeción (ver figura 3.7).

El tramo de calibración es el marcado según estandar, sobre el cual se miden las lecturas de longitud final y diámetro final los extremos de las probetas redondas, y rectangulares, pueden ser simples, cabeceados o roscados, los extremos simples deben ser largos para adaptarse algún tipo de mordaza cuneiforme o plana (ver figura 3.8).



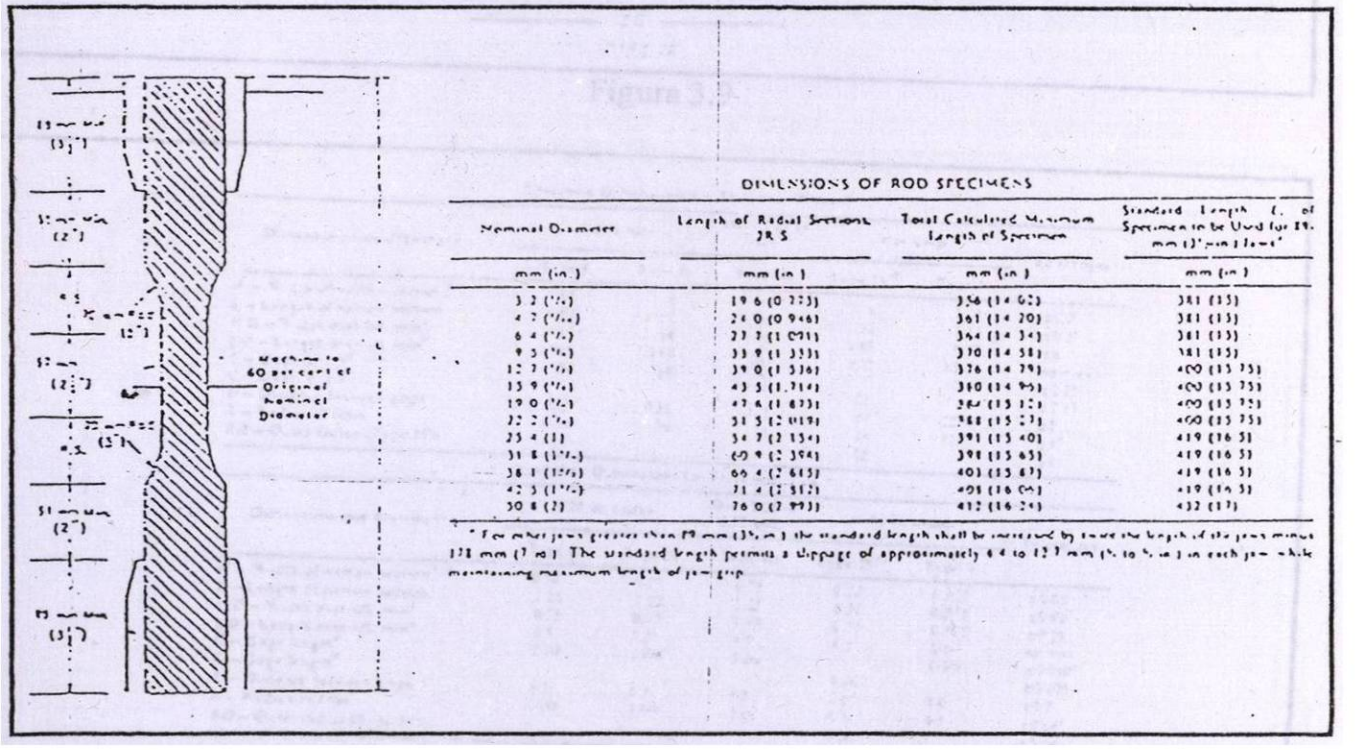
Dimensions

| | Specimen 1 | Specimen 2 | Specimen 3 |
|---|---|---|---|
| | in. | in. | in. |
| G—Length of parallel section | Shall be equal to or greater than diameter D | | |
| D—Diameter | 0.500 ± 0.010 | 0.750 ± 0.015 | 1.25 ± 0.02 |
| R—Radius of fillet, min | ¼ | ½ | 2 |
| A—Length of reduced section, min | 1¼ | 1½ | 2½ |
| L—Overall length, min | 3½ | 4 | 6¾ |
| E—Length of end section, approximate | 1 | 1 | 1½ |
| C—Diameter of end section, approximate | ⅝ | 1⅛ | 1⅜ |
| S—Length of threads, min | ¾ | ¾ | ¾ |
| F—Diameter of threads | ½ − 13 | ¾ − 10 | 1 − 8 |

NOTE—The reduced section and shoulder fillet dimensions A, D, S, F, G, and R shall be as shown but the ends may be of any form to fit the holders of the testing machine in such a way that the load can be axial. Commonly the ends are threaded and have the dimensions B and C given above.

Standard Tension Test Specimen for Cast Iron

Figura 3.7



DIMENSIONS OF ROD SPECIMENS

| Nominal Diameter | Length of Radial Sections, R S | Total Calculated Minimum Length of Specimen | Standard Length L of Specimen to be Used for 19 mm (¾ in.) and Smaller Bars* |
|---|---|---|---|
| mm (in.) | mm (in.) | mm (in.) | mm (in.) |
| 3.2 (⅛) | 19.6 (0.773) | 356 (14.02) | 381 (15) |
| 4.7 (⅜) | 24.0 (0.946) | 361 (14.20) | 381 (15) |
| 6.4 (¼) | 27.7 (1.091) | 364 (14.34) | 381 (15) |
| 9.5 (⅜) | 33.9 (1.333) | 370 (14.58) | 381 (15) |
| 12.7 (½) | 39.0 (1.536) | 376 (14.79) | 400 (15.75) |
| 15.9 (⅝) | 43.5 (1.714) | 380 (14.95) | 400 (15.75) |
| 19.0 (¾) | 47.4 (1.873) | 384 (15.12) | 400 (15.75) |
| 22.2 (⅞) | 51.5 (2.028) | 388 (15.27) | 400 (15.75) |
| 25.4 (1) | 54.7 (2.154) | 391 (15.40) | 419 (16.5) |
| 31.8 (1¼) | 60.9 (2.398) | 398 (15.65) | 419 (16.5) |
| 38.1 (1½) | 66.4 (2.615) | 403 (15.87) | 419 (16.5) |
| 44.5 (1¾) | 71.4 (2.812) | 408 (16.06) | 419 (16.5) |
| 50.8 (2) | 76.0 (2.993) | 412 (16.24) | 432 (17) |

* For rods or bars greater than 19 mm (¾ in.) the standard length shall be increased by twice the length of the grips minus 127 mm (5 in.). The standard length permits a slippage of approximately 6.4 to 12.7 mm (¼ to ½ in.) in each jaw while maintaining maximum length of jaw grip.

Figura 3.8

Una probeta debe ser simétrica con respecto a un eje longitudinal a lo largo de su longitud para evitar la flexión durante la aplicación de la carga (ver figura 3.8), la longitud de la sección reducida depende de la clase de material y de las mediciones que se tomen.

En las siguientes figuras 3.9 y 3.10 se muestran los diferentes estándares para los ensayos estáticos de tensión.

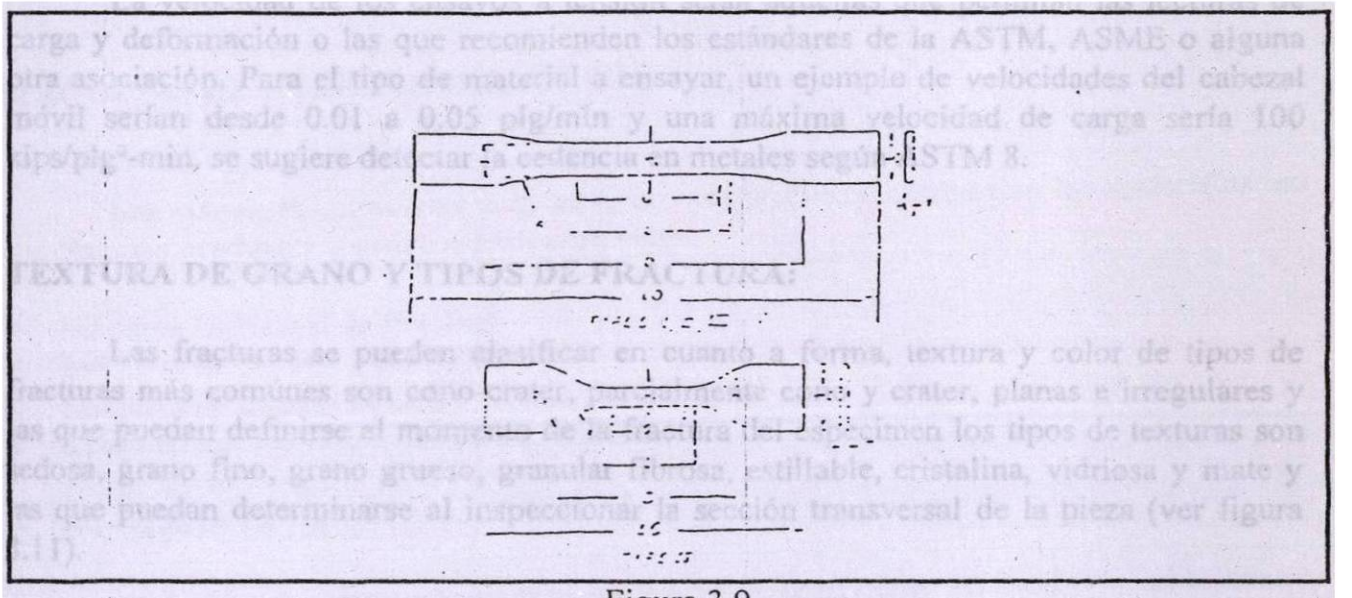


Figura 3.9

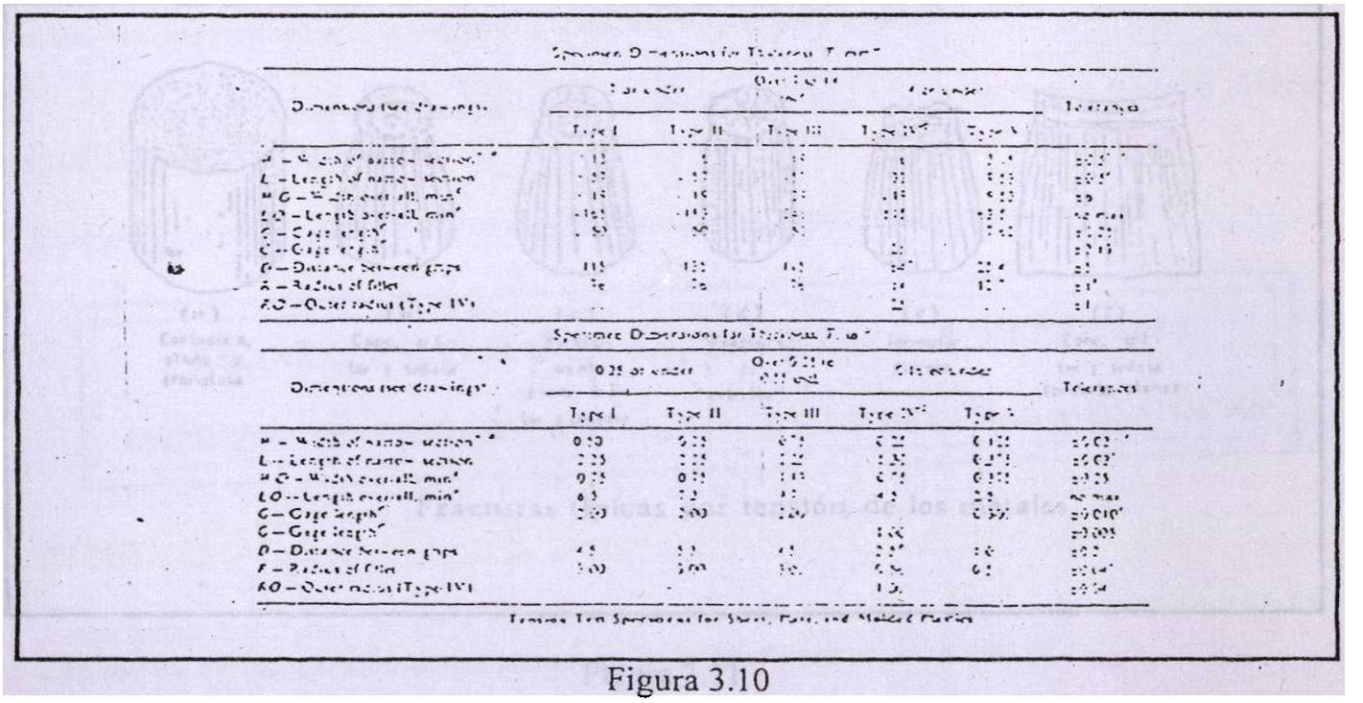


Figura 3.10

Otros estándares para polímeros o plásticos se encuentran en la asignación de la ASTM D 412, hasta D 530, hasta D 638; para concreto ASTM C 190; para materiales eléctricos ASTM D 651, etc.

## VELOCIDAD EN ENSAYOS DE TENSIÓN

La velocidad de los ensayos a tensión serán aquellas que permitan las lecturas de carga y deformación o las que recomienden los estándares de la ASTM, ASME o alguna otra asociación. Para el tipo de material a ensayar, un ejemplo de velocidades del cabezal móvil serían desde 0.01 a 0.05 plg/min y una máxima velocidad de carga sería 100 kips/plg$^2$-min, se sugiere detectar la cedencia en metales según ASTM 8.

## TEXTURA DE GRANO Y TIPOS DE FRACTURA:

Las fracturas se pueden clasificar en cuanto a forma, textura y color de tipos de fracturas más comúnes son cono-crater, parcialmente cono y crater, planas e irregulares y las que puedan definirse al momento de la fractura del especimen los tipos de texturas son sedosa, grano fino, grano grueso, granular fibrosa, estillable, cristalina, vidriosa y mate y las que puedan determinarse al inspeccionar la sección transversal de la pieza (ver figura 3.11).

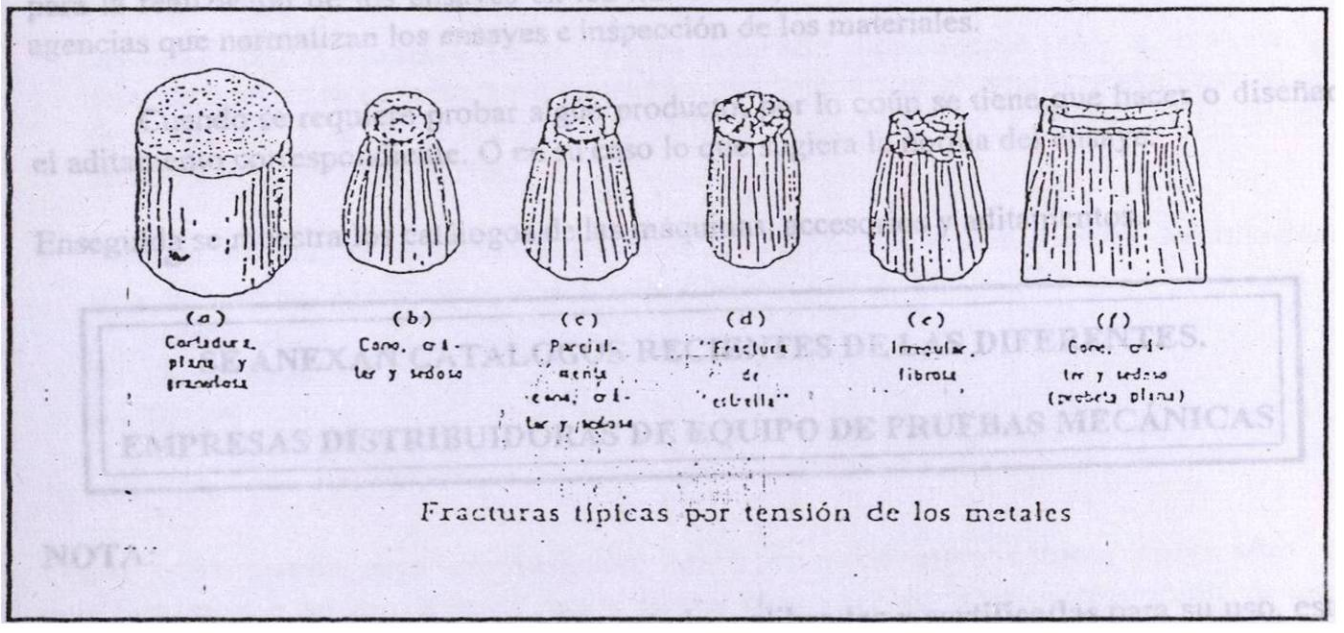



Figura 3.11

# 4.- Máquinas para Pruebas Mecánicas, Accesorios e Instrumentos de Medición

## MÁQUINAS DE PRUEBAS MECÁNICAS

Las máquinas empleadas para las diferentes pruebas o ensayes en los materiales, en los diversos productos y pruebas experimentales.

* Máquina Universal de Pruebas
* Máquina de Dureza Rockwell
* Máquina de Dureza Brinell
* Máquina de Ductilidad en la Mina Metálica
* Máquina de Torsión
* Máquina de Fatiga

Cada una de estas máquinas tiene sus correspondientes accesorios o aditamentos para la realización de los ensayes en los materiales, los cuales son recomendados por las agencias que normalizan los ensayes e inspección de los materiales.

Cuando se requiere probar algún producto, por lo coún se tiene que hacer o diseñar el aditamento correspondiente. O en su caso lo que sugiera la norma del ensaye.

Enseguida se muestra los catálogos de las máquinas, accesorios y aditamentos.

**SE ANEXAN CATALOGOS RECIENTES DE LAS DIFERENTES.**

**EMPRESAS DISTRIBUIDORAS DE EQUIPO DE PRUEBAS MECÁNICAS**

## NOTA:

Estas máquinas deben de estar en **buen estado, calibradas y certificadas** para su uso, esto dependerá de las recomendaciones que haga el fabricante de las mismas.

## INSTRUMENTOS DE MEDICIÓN

Los instrumentos de medición que se requieren para obtener los datos iniciales y finales sobre el especimen o muestra son:

* **Calibrador para lecturas de dimensiones lineales de tipo:**
  1. Vernier
  2. De Carátula
  3. Digitales

* **Cinta métrica o flexómetro**

* **Calibrador de tipo micrometros** para la lectura de espesores interiores y exteriores.

* **Extensometro** para la medición de desplazamientos lineales de:
  1. Carátula
  2. Digitales

* **Indicador de deformación (Puente de Wheatstone)** Considerando los **Straingages** o medidores de deformación eléctricos que se pegan o instrumentan en la pieza a probar para determinar la deformación punto por punto y en cualquier dirección que se desee o se requiera.

* **Medidor de deformación eléctrico** para colocarlo directamente sobre el material y detectar a treves del graficador o en pantalla del monitor de la microcomputadora, si se tiene una máquina programable (automatizada por medio del software) el punto de cedencia del material a probar.

* **Planímetro:** para la obtención de las áreas de la gráfica de esfuerzo contra deformación para determinar la resilencia, tenacidad unitarios y pueden ser del tipo:
  1. Mecánico
  2. De Carátula
  3. Digital

**NOTA:**

Todos estos instrumentos de medición deben estar en **buen estado, calibrados y certificados** para su uso al igual que si tienen caducidad verificar su reposición ya que influyen en los resultados de las características dimensionales de la pieza o especimen, al igual que en las propiedades y características mecánicas del material o producto.

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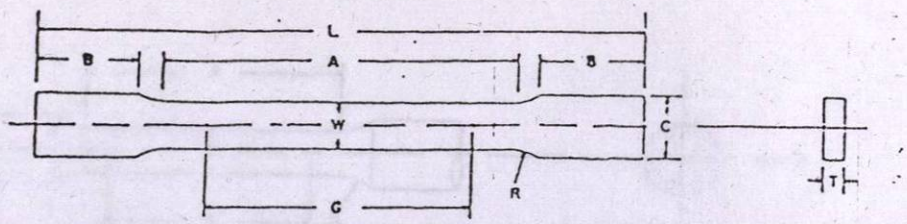
7. MATERIALES PARA INGENIERÍA.
AUTOR: VAN BLACK.




Dimensions, mm

| Nominal Width | Standard Specimens | | Subsize Specimen |
|---|---|---|---|
| | Plate-Type 40 mm | Sheet-Type 12.5 mm | 6 mm |
| G—Gage length (Notes 1 and 2) | 200.0 ± 0.2 | 50.0 ± 0.1 | 25.0 ± 0.1 |
| W—Width (Notes 3 and 4) | 40.0 ± 2.0 | 12.5 ± 0.2 | 6.0 ± 0.1 |
| T— Thickness (Note 5) | | thickness of material | |
| R— Radius of fillet, min (Note 6) | 25 | 12.5 | 6 |
| L— Overall length, min (Notes 2 and 7) | 450 | 200 | 100 |
| A— Length of reduced section, min | 225 | 57 | 32 |
| B— Length of grip section, min (Note 8) | 75 | 50 | 30 |
| C— Width of grip section, approximate (Notes 4 and 9) | 50 | 20 | 10 |

NOTE 1—For the 40-mm wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within reduced section. Either a set of nine or more punch marks 25 mm apart, or one or more pairs of punch marks 200 mm apart, may be used.

NOTE 2—When elongation measurements of 40-mm wide specimens are not required, a minimum length of reduced section (*A*) of 75 mm may be used with all oth dimensions similar to the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.05 or 0.02 mm, respectively. Also, there m be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases the width of the reduced section sho be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not ap when these narrower specimens are used.

NOTE 5—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40-mm wide specime shall be 5 mm. Maximum thickness of 12.5-mm and 6-mm wide specimens shall be 19 mm and 6 mm, respectively.

NOTE 6—For the 40-mm wide specimen, a 13-mm minimum radius at the ends of the reduced section is permitted for steel specimens under 690 MPa in tensile stren when a profile cutter is used to machine the reduced section.

NOTE 7—To aid in obtaining axial loading during testing of 6-mm wide specimens, the overall length should be as large as the material will permit, but in [illegible] mm.

NOTE 8—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds more of the length of the grips. If the thickness of 12.5-mm wide specimens is over 10 mm, longer grips and correspondingly longer end sections of the specimen may necessary to prevent failure in the grip section.

NOTE 9—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 2.5, 0.25, and 0. mm, respectively. However, for referee testing and when required by product specifications, the ends of the 12.5-mm wide specimen shall be symmetrical within 0.2 m

NOTE 10—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (a) the above tolerances are used; (b) an adequa number of marks are provided for determination of elongation; and (c) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at distance of less than 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if t properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 1 Rectangular Tension Test Specimens

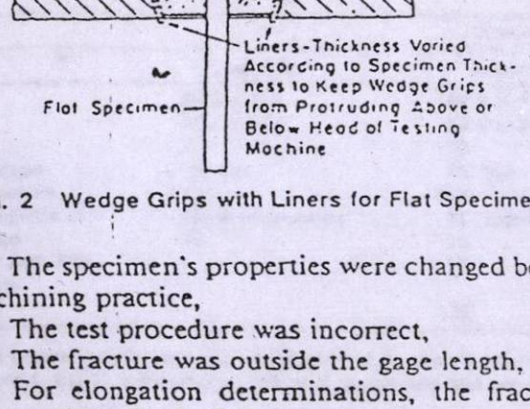



FIG. 2 Wedge Grips with Liners for Flat Specimens

7.10.3 The specimen's properties were changed because of poor machining practice,

7.10.4 The test procedure was incorrect,

7.10.5 The fracture was outside the gage length,

7.10.6 For elongation determinations, the fracture was outside the middle half of the gage length, or

7.10.7 There was a malfunction of the testing equipment.

NOTE 26—The tension specimen is inappropriate for assessing some types of imperfections in a material. Other methods and specimens employing ultrasonics, dye penetrants, radiography, etc., may be considered when flaws such as cracks, flakes, porosity, etc., are revealed during a test and soundness is a condition of acceptance.

## 8. Report

8.1 Test information on materials not covered by product specification should be reported in accordance wit 8.2 or both 8.2 and 8.3.

8.2 Test information to be reported shall include th following when applicable:

8.2.1 Material and sample identification.

8.2.2 Specimen type (Section 6).

8.2.3 Yield strength and the method used to determin yield strength (see 7.4).

8.2.4 Yield point and the method used to determine yiel point (see 7.5).

8.2.5 Tensile strength (see 7.6).

8.2.6 Elongation (report both the original gage length an the percentage increase) (see 7.7).

8.2.7 Reduction of area (see 7.8).

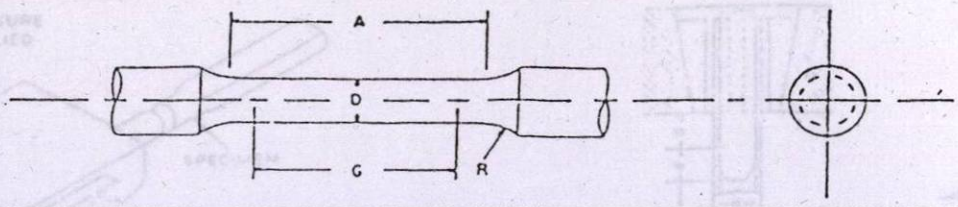
8.3 Test information to be available on request sha include:

8.3.1 Specimen test section dimension(s).

8.3.2 Formula used to calculate cross-sectional area c specimens taken from large-diameter tubular products.

8.3.3 Speed and method used to determine speed c testing (see 7.3).

8.3.4 Method used for rounding of test results (see 7.9).




| | Dimensions, mm | | | | |
|---|---|---|---|---|---|
| | Standard Specimen | Small-Size Specimens Proportional To Standard | | | |
| | 12.5 | 9 | 6 | 4 | 2.5 |
| — Gage length | 62.5 ± 0.1 | 45.0 ± 0.1 | 30.0 ± 0.1 | 20.0 ± 0.1 | 12.5 ± 0.1 |
| — Diameter (Note 1) | 12.5 ± 0.2 | 9.0 ± 0.1 | 6.0 ± 0.1 | 4.0 ± 0.1 | 2.5 ± 0.1 |
| — Radius of fillet, min | 10 | 8 | 6 | 4 | 2 |
| — Length of reduced section, min (Note 2) | 75 | 54 | 36 | 24 | 20 |

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center (controlling mension).

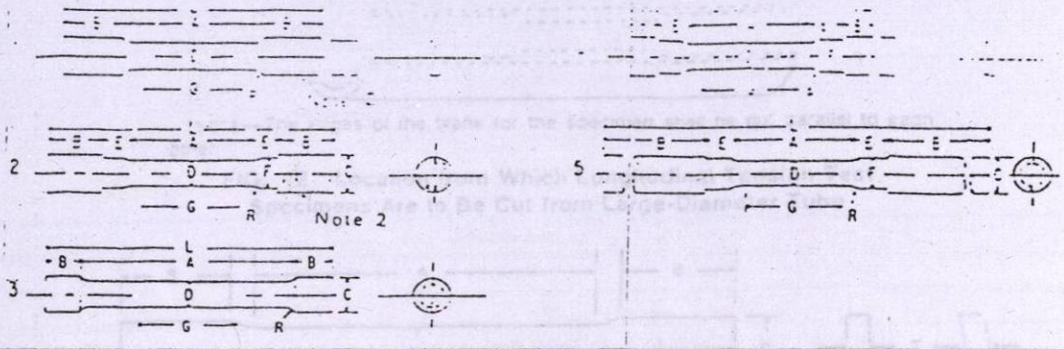
NOTE 2—If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference marks for the easurement of elongation should, nevertheless, be spaced at the indicated gage length.

NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load may be ial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend o the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—On the round specimens in Figs. 8 and 9, the gage lengths are equal to five times the nominal diameter. In some product specifications other specimens may provided for, but the 5-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test ecimen.

NOTE 5—The use of specimens smaller than 6 mm in diameter shall be restricted to cases when the material to be tested is of insufficient size to obtain larger ecimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both machining and testing.

G. 8 Standard 12.5-mm Round Tension Test Specimen with Gage Lengths Five Times the Diameters (5D), and Examples of Small-Size Specimens Proportional to the Standard Specimen




| | Dimensions, mm | | | | |
|---|---|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 | Specimen 4 | Specimen 5 |
| Gage length | 62.5 ± 0.1 | 62.5 ± 0.1 | 62.5 ± 0.1 | 62.5 ± 0.1 | 62.5 ± 0.1 |
| Diameter (Note 1) | 12.5 ± 0.2 | 12.5 ± 0.2 | 12.5 ± 0.2 | 12.5 ± 0.2 | 12.5 ± 0.2 |
| Radius of fillet, min | 10 | 10 | 2 | 10 | 10 |
| Length of reduced section | 75, min | 75, min | 100, approximately | 75, min | 75, min |
| Overall length, approximate | 145 | 155 | 140 | 140 | 255 |
| Length of end section (Note 3) | 35, approximately | 25, approximately | 20, approximately | 15, approximately | 75, min |
| Diameter of end section | 20 | 20 | 20 | 22 | 20 |
| Length of shoulder and fillet section, approximate | .... | 15 | .... | 20 | 15 |
| Diameter of shoulder | .... | 15 | .... | 15 | 15 |

E 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center.

E 2—On Specimens 1 and 2, any standard thread is permissible that provides for proper alignment and aids in assuring that the specimen will break within the d section.

E 3—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal thirds or more of the length of the grips.

FIG. 9 Various Types of Ends for Standard Round Tension Test Specimens

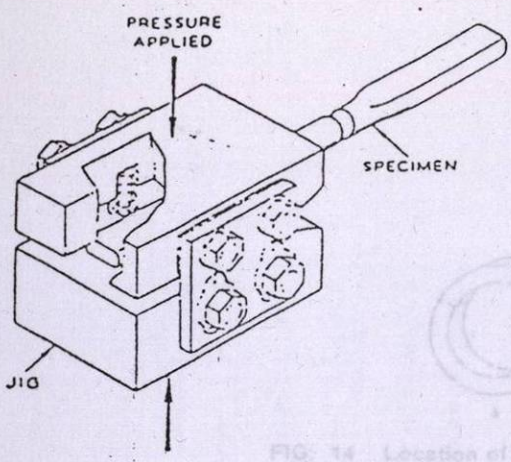
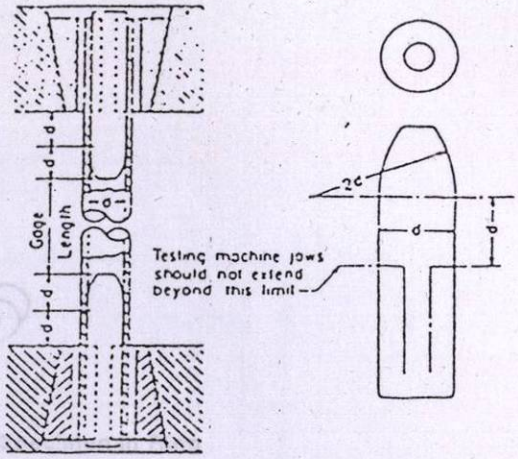
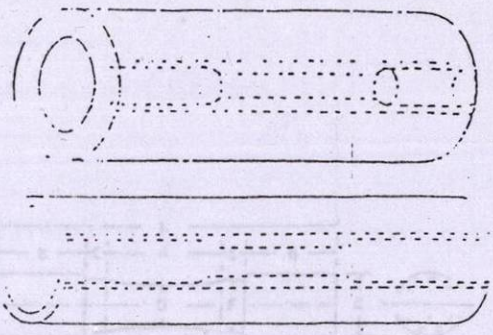



FIG. 10 Squeezing Jig for Flattening Ends of Full-Size Tension?? Test Specimens



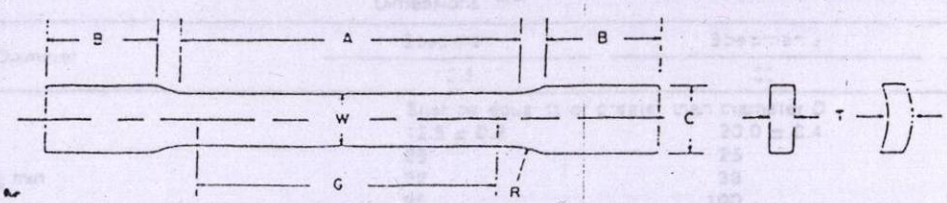

NOTE—The diameter of the plug shall have a slight taper from the line limiting the testing machine jaws to the curved section.

FIG. 11 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine



NOTE—The edges of the blank for the specimen shall be cut parallel to each other.

FIG. 12 Location from Which Longitudinal Tension Test Specimens Are to Be Cut from Large-Diameter Tube




| Dimensions, mm | | | |
|---|---|---|---|
| Nominal Width | Specimen 1 | Specimen 2 | Specimen 3 |
| | 12.5 | 40 | 40 |
| G—Gage length | 50.0 ± 0.1 | 50.0 ± 0.1 | 200.0 ± 0.2 |
| W—Width (Note 1) | 12.5 ± 0.2 | 40.0 ± 2.0 | 40.0 ± 2.0 |
| T—Thickness | measured thickness of specimen | | |
| R—Radius of fillet, min | 12.5 | 25 | 25 |
| —Length of reduced section, min | 60 | 60 | 230 |
| —Length of grip section, min (Note 2) | 75 | 75 | 75 |
| —Width of grip section, approximate (Note 3) | 20 | 50 | 50 |

NOTE 1—The ends of the reduced section shall not differ in width by more than 0.1 mm for specimens 1, 2, and 3. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

NOTE 2—It is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 3—The ends of the specimen shall be symmetrical with the center line of the reduced section within 1.0 mm for specimen 1 and 2.5 mm for specimens 2 and 3.

NOTE 4—Specimens with sides parallel throughout their length are permitted, except for referee testing and where prohibited by product specification, provided: (*a*) the more precise tolerances are used; (*b*) an adequate number of marks are provided for determination of elongation; and (*c*) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the specimen and retest.

FIG. 13 Tension Test Specimens for Large-Diameter Tubular Products

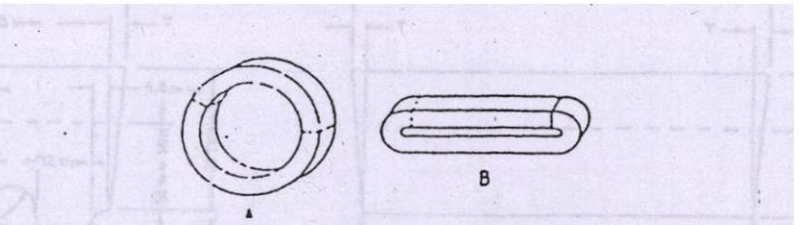
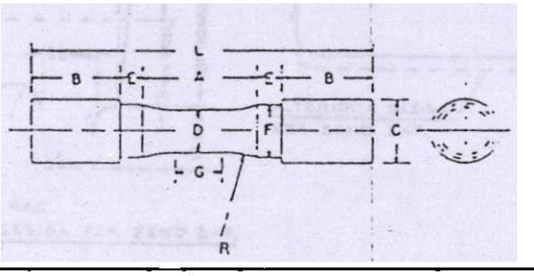


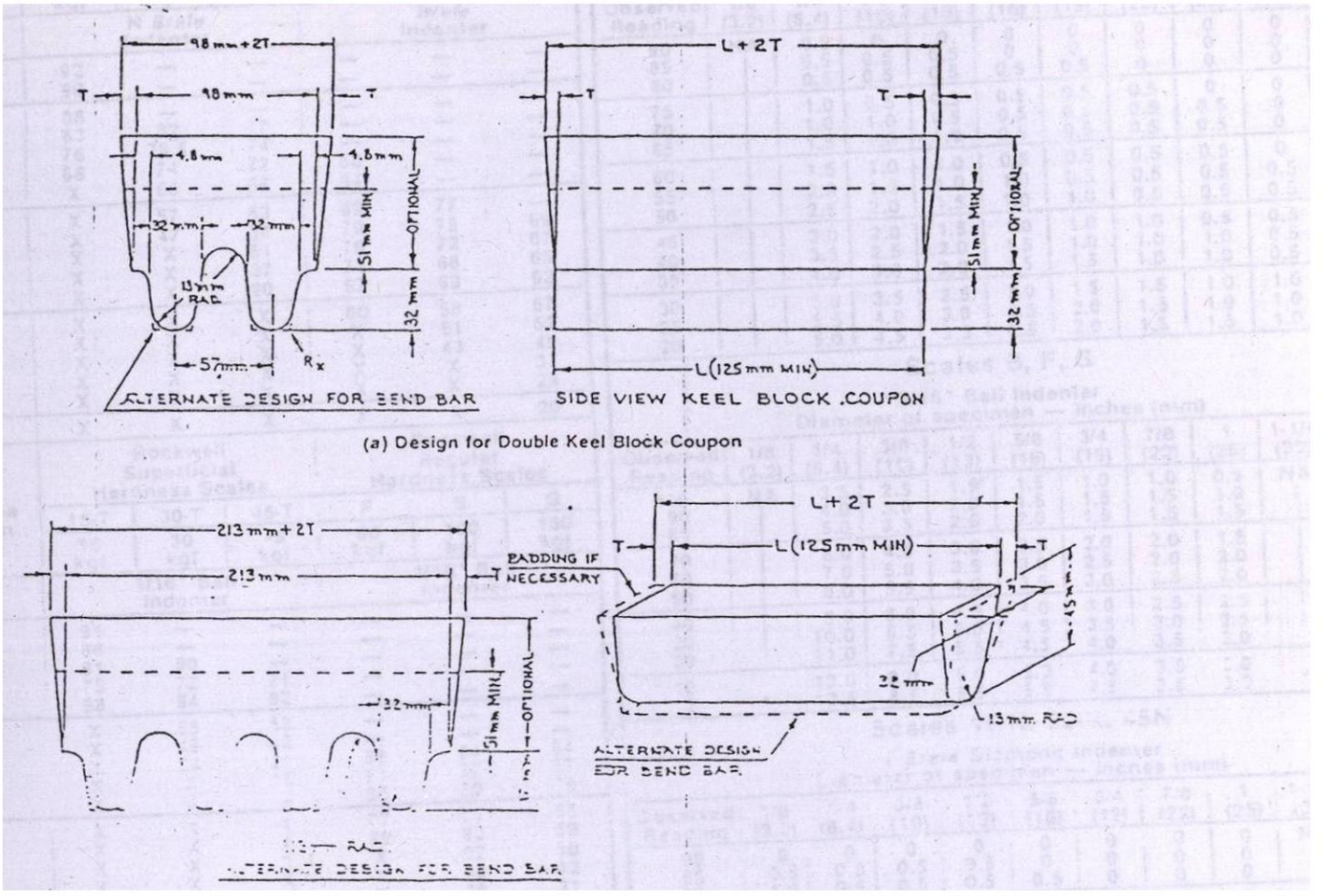

FIG. 14 Location of Transverse Tension Test Specimen in Ring Cut from Tubular Products




| Nominal Diameter | Dimensions, mm | | |
|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 |
| | 13.5 | 20 | 30 |
| G—Length of parallel | Shall be equal to or greater than diameter D | | |
| D—Diameter | 13.5 ± 0.2 | 20.0 ± 0.4 | 30.0 ± 0.6 |
| R—Radius of fillet, min | 25 | 25 | 50 |
| A—Length of reduced section, min | 32 | 38 | 60 |
| L—Overall length, min | 95 | 100 | 160 |
| B—Length of end section, approximate | 25 | 25 | 45 |
| C—Diameter of end section, approximate | 20 | 30 | 48 |
| E—Length of shoulder, min | 6 | 6 | 8 |
| F—Diameter of shoulder | 16.0 ± 0.4 | 24.0 ± 0.4 | 36.5 ± 0.4 |

NOTE—The reduced section and shoulders (dimensions *A*, *D*, *E*, *F*, *G*, and *R*) shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. Commonly the ends are threaded and have the dimensions *B* and *C* given above.

FIG. 15 Standard Tension Test Specimen for Cast Iron

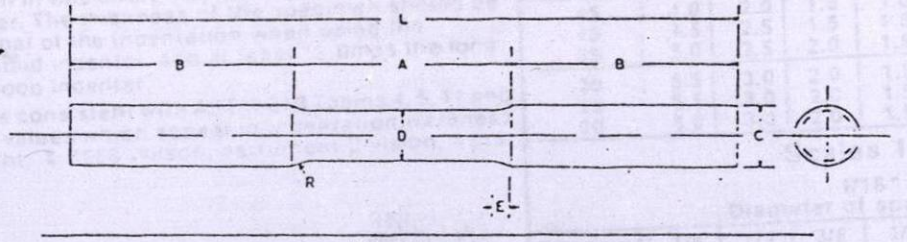



(a) Design for Double Keel Block Coupon

(b) Design for Multiple Keel Block Coupon (4 Legs)

(c) Design for "Attached" Coupon

FIG. 16 Test Coupons for Castings (see Table 1 for Details of Design)




| Dimensions, mm | |
|---|---|
| *D*—Diameter | 16 |
| *R*—Radius of fillet | 8 |
| *A*—Length of reduced section | 64 |
| *L*—Overall length | 190 |
| *B*—Length of end section | 64 |
| *C*—Diameter of end section | 20 |
| *E*—Length of fillet | 5 |

FIG. 17 Standard Tension Test Specimen for Malleable Iron

## rdness vs Minimum Thickness Chart 55

| r greater kness and dness can be ely tested on icated scale | Rockwell Superficial Hardness Scales | | | Rockwell Regular Hardness Scales | | |
|---|---|---|---|---|---|---|
| | 15N | 30N | 45N | A | D | C |
| | 15 kgf | 30 kgf | 45 kgf | 60 kgf | 100 kgf | 150 kgf |
| Thickness nches (mm) | N *Brale* Indenter | | | *Brale* Indenter | | |
| .006 (0.15) | 92 | — | — | — | — | — |
| .008 (0.20) | 90 | — | — | — | — | — |
| .010 (0.25) | 88 | — | — | — | — | — |
| .012 (0.30) | 83 | 82 | 77 | — | — | — |
| .014 (0.36) | 76 | 78.5 | 74 | — | — | — |
| .016 (0.41) | 68 | 74 | 72 | 86 | — | — |
| .018 (0.46) | X | 66 | 68 | 84 | — | — |
| .020 (0.51) | X | 57 | 63 | 82 | 77 | — |
| .022 (0.56) | X | 47 | 58 | 79 | 75 | 69 |
| .024 (0.61) | X | X | 51 | 76 | 72 | 67 |
| .026 (0.66) | X | X | 37 | 71 | 68 | 65 |
| .028 (0.71) | X | X | 20 | 67 | 63 | 62 |
| .030 (0.76) | X | X | X | 60 | 58 | 57 |
| .032 (0.81) | X | X | X | X | 51 | 52 |
| .034 (0.86) | X | X | X | X | 43 | 45 |
| .036 (0.91) | X | X | X | X | X | 37 |
| .038 (0.96) | X | X | X | X | X | 28 |
| .040 (1.02) | X | X | X | X | X | 20 |

| y greater kness and dness can be ely tested on icated scale | Rockwell Superficial Hardness Scales | | | Rockwell Regular Hardness Scales | | |
|---|---|---|---|---|---|---|
| | 15-T | 30-T | 45-T | F | B | G |
| | 15 kgf | 30 kgf | 45 kgf | 60 kgf | 100 kgf | 150 kgf |
| Thickness nches (mm) | 1/16" Ball Indenter | | | 1/16" Ball Indenter | | |
| .010 (0.25) | 91 | — | — | — | — | — |
| .012 (0.30) | 86 | — | — | — | — | — |
| .014 (0.36) | 81 | 80 | — | — | — | — |
| .016 (0.41) | 75 | 72 | 71 | — | — | — |
| .018 (0.46) | 68 | 64 | 62 | — | — | — |
| .020 (0.51) | X | 55 | 53 | — | — | — |
| .022 (0.56) | X | 45 | 43 | — | — | — |
| .024 (0.61) | X | 34 | 31 | 99 | 94 | 94 |
| .026 (0.66) | X | X | 19 | 91 | 87 | 87 |
| .028 (0.71) | X | X | 1 | 85 | 80 | 78 |
| .030 (0.76) | X | X | X | 77 | 71 | 68 |
| .032 (0.81) | X | X | X | 69 | 62 | 59 |
| .034 (0.86) | X | X | X | X | 52 | 50 |
| .036 (0.91) | X | X | X | X | 40 | 42 |
| .038 (0.96) | X | X | X | X | 28 | 31 |
| .040 (1.02) | X | X | X | X | X | 22 |

o Minimum Hardness

se values are approximate only and this chart is intended primarily guide.

erials thinner than shown in this chart may be tested on the on't microhardness tester. The thickness of the specimen should be east 1½ times the diagonal of the indentation when using the ers (136°) diamond pyramid indenter, and at least ½ times the long gonal when using the Knoop indenter.

e 3: Values in Chart 55 are consistent with ASTM E18 Tables 4, 5, 11 and xcept for D and G-scale values which appear in *Indentation Hardness ting* by Vincent E. Lysaght, © 1968 Wilson Instrument Division, Acco

## Cylindrical Correction Chart 53

Cylindrical work corrections to be added to observed Rockwell Number for Scales Indicated

### Scales C, D, A

*Brale* Diamond Indenter
Diameter of specimen — Inches (mm)

| Observed Reading | 1/8 (3.2) | 1/4 (6.4) | 3/8 (10) | 1/2 (13) | 5/8 (16) | 3/4 (19) | 7/8 (22) | 1 (25) | 1-1/4 (32) | 1-1/2 (38) |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | NA | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85 | | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 80 | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 | 0 |
| 75 | | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 |
| 70 | | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 |
| 65 | | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 |
| 60 | | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 |
| 55 | | 2.0 | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0 |
| 50 | | 2.5 | 2.0 | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 |
| 45 | | 3.0 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 |
| 40 | | 3.5 | 2.5 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | 0.5 | 0.5 |
| 35 | | 4.0 | 3.0 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 |
| 30 | | 5.0 | 3.5 | 2.5 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 | 0.5 |
| 25 | | 5.5 | 4.0 | 3.0 | 2.5 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 |
| 20 | ↓ | 6.0 | 4.5 | 3.5 | 2.5 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 |

### Scales B, F, G

1/16" Ball Indenter
Diameter of specimen — inches (mm)

| Observed Reading | 1/8 (3.2) | 1/4 (6.4) | 3/8 (10) | 1/2 (13) | 5/8 (16) | 3/4 (19) | 7/8 (22) | 1 (25) | 1-1/4 (32) | 1-1/2 (38) |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | NA | 3.5 | 2.5 | 1.5 | 1.5 | 1.0 | 1.0 | 0.5 | NA | NA |
| 90 | | 4.0 | 3.0 | 2.0 | 1.5 | 1.5 | 1.5 | 1.0 | | |
| 80 | | 5.0 | 3.5 | 2.5 | 2.0 | 1.5 | 1.5 | 1.5 | | |
| 70 | | 6.0 | 4.0 | 3.0 | 2.5 | 2.0 | 2.0 | 1.5 | | |
| 60 | | 7.0 | 5.0 | 3.5 | 3.0 | 2.5 | 2.0 | 2.0 | | |
| 50 | | 8.0 | 5.5 | 4.0 | 3.5 | 3.0 | 2.5 | 2.0 | | |
| 40 | | 9.0 | 6.0 | 4.5 | 4.0 | 3.0 | 2.5 | 2.5 | | |
| 30 | | 10.0 | 6.5 | 5.0 | 4.5 | 3.5 | 3.0 | 2.5 | | |
| 20 | | 11.0 | 7.5 | 5.5 | 4.5 | 4.0 | 3.5 | 3.0 | | |
| 10 | | 12.0 | 8.0 | 5.0 | 5.0 | 4.0 | 3.5 | 3.0 | | |
| 1 | ↓ | 12.5 | 8.5 | 6.5 | 5.5 | 4.5 | 3.5 | 3.0 | | |

### Scales 15-N, 30-N, 45N

*Brale* Diamond Indenter
Diameter of specimen — inches (mm)

| Observed Reading | 1/8 (3.2) | 1/4 (6.4) | 3/8 (10) | 1/2 (13) | 5/8 (16) | 3/4 (19) | 7/8 (22) | 1 (25) | 1-1/4 (32) | 1-1/2 (38) |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA | NA |
| 85 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 | 0 | | |
| 80 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | 0 | | |
| 75 | 1.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0 | 0 | | |
| 70 | 2.0 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | |
| 65 | 2.5 | 1.5 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | | |
| 60 | 3.0 | 1.5 | 1.0 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | | |
| 55 | 3.5 | 2.0 | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | | |
| 50 | 3.5 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | 1.0 | 0.5 | | |
| 45 | 4.0 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| 40 | 4.5 | 2.5 | 1.5 | 1.5 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| 35 | 5.0 | 2.5 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| 30 | 5.5 | 3.0 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 | 1.0 | | |
| 25 | 5.5 | 3.0 | 2.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.0 | | |
| 20 | 6.0 | 3.0 | 2.0 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | ↓ | ↓ |

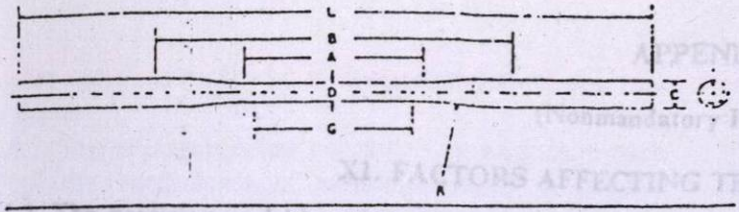
### Scales 15-T, 30-T, 45-T

1/16" Ball Indenter
Diameter of specimen — inches (mm)

| Observed Reading | 1/8 (3.2) | 1/4 (6.4) | 3/8 (10) | 1/2 (13) | 5/8 (16) | 3/4 (19) | 7/8 (22) | 1 (25) | 1-1/4 (32) | 1-1/2 (38) |
|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 1.5 | 1.0 | 1.0 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | NA | NA |
| 80 | 3.0 | 2.0 | 1.5 | 1.5 | 1.0 | 1.0 | 1.0 | 0.5 | | |
| 70 | 5.0 | 3.5 | 2.5 | 2.0 | 1.5 | 1.0 | 1.0 | 1.0 | | |
| 60 | 6.5 | 4.5 | 3.0 | 2.5 | 2.0 | 1.5 | 1.5 | 1.5 | | |
| 50 | 8.5 | 5.5 | 4.0 | 3.0 | 2.5 | 2.0 | 2.0 | 1.5 | | |
| 40 | 10.0 | 6.5 | 4.5 | 3.5 | 3.0 | 2.5 | 2.0 | 2.0 | | |
| 30 | 11.5 | 7.5 | 5.0 | 3.5 | 3.5 | 2.5 | 2.0 | 2.0 | | |
| 20 | 13.0 | 9.0 | 6.0 | 4.5 | 4.5 | 3.0 | 2.0 | 2.0 | ↓ | ↓ |

These corrections are approximate only and represent the averages, to the nearest 1/2 Rockwell number, of numerous actual observations. These values are consistent with ASTM E18 Tables 6, 7, 13 and 14.

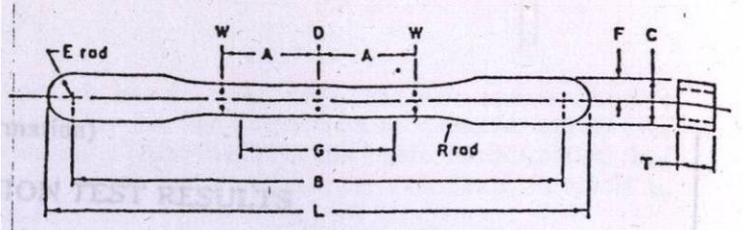
When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, Vee anvil, indenters, surface finish and the straightness of the cylinder.




| Dimensions, mm | |
|---|---|
| *G*—Gage length | 50.0 ± 0.1 |
| *D*—Diameter (see Note) | 6.4 ± 0.1 |
| *R*—Radius of fillet, min | 75 |
| *A*—Length of reduced section, min | 60 |
| *L*—Overall length, min | 230 |
| *B*—Distance between grips, min | 115 |
| *C*—Diameter of end section, approximate | 10 |

NOTE—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 0.1 mm larger in diameter than the center.

FIG. 18 Standard Tension Test Specimen for Die Castings

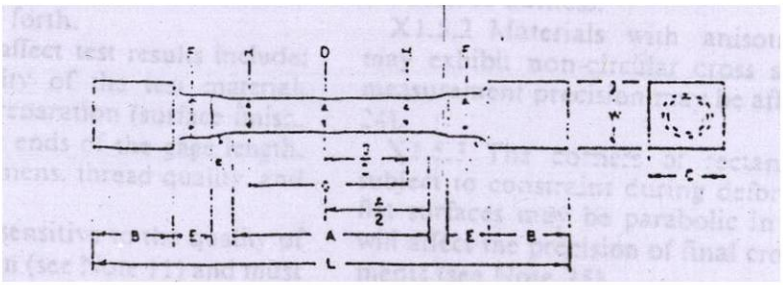



Pressing Area = 645 mm²

NOTE—Dimensions specified, except G and T, are those of the die.

| Dimensions, mm | |
|---|---|
| *G*—Gage length | 25.40 ± 0.8 |
| *D*—Width at center | 5.72 ± 0.03 |
| *W*—Width at end of reduced section | 5.97 ± 0.03 |
| *T*—Compact to this thickness | 3.56 to 6.35 |
| *R*—Radius of fillet | 25.4 |
| *A*—Half-length of reduced section | 15.88 |
| *B*—Grip length | 80.95 ± 0.03 |
| *L*—Overall length | 89.64 ± 0.03 |
| *C*—Width of grip section | 8.71 ± 0.03 |
| *F*—Half-width of grip section | 4.34 ± 0.03 |
| *E*—End radius | 4.34 ± 0.03 |

FIG. 19 Standard Flat Unmachined Tension Test Specimen for Powder Metallurgy (P/M) Products




**Approximate Pressing Area of Unmachined Compact = 752 mm²**

**Machining Recommendations**

1. Rough machine reduced section to 6.35 mm diameter
2. Finish turn 4.75/4.85 mm diameter with radii and taper
3. Polish with 00 emery cloth
4. Lap with crocus cloth

| Dimensions, mm | |
|---|---|
| *G*—Gage length | 25.40 ± 0.8 |
| *D*—Diameter at center of reduced section | 4.75 ± 0.03 |
| *H*—Diameter at ends of gage length | 4.85 ± 0.03 |
| *R*—Radius of fillet | 6.35 ± 0.13 |
| *A*—Length of reduced section | 47.63 ± 0.13 |
| *L*—Overall length (die cavity length) | 75, nominal |
| *B*—Length of end section | 7.88 ± 0.13 |
| *C*—Compact to this end thickness | 10.03 ± 0.13 |
| *W*—Die cavity width | 10.03 ± 0.08 |
| *E*—Length of shoulder | 6.35 ± 0.13 |
| *F*—Diameter of shoulder | 7.88 ± 0.03 |
| *J*—End fillet radius | 1.27 ± 0.13 |

NOTE 1—The gage length and fillets of the specimen shall be as shown. The ends as shown are designed to provide a practical minimum pressing area. Other end designs are acceptable, and in some cases are required for high-strength sintered materials.

NOTE 2—It is recommended that the test specimen be gripped with a split collet and supported under the shoulders. The radius of the collet support circular edge is to be not less than the end fillet radius of the test specimen.

NOTE 3—Diameters *D* and *H* are to be concentric within 0.03 mm total indicator runout (T.I.R.), and free of scratches and tool marks.

FIG. 20 Standard Round Machined Tension Test Specimen for Powder Metallurgy (P/M) Products

## APPENDIX

(Nonmandatory Information)

## X1. FACTORS AFFECTING TENSION TEST RESULTS

X1.1 The precision and bias of tension test strength and ductility measurements depend on strict adherence to the stated test procedure and are influenced by instrumental and material factors, specimen preparation, and measurement/testing errors.

X1.2 The consistency of agreement for repeated tests of the same material is dependent on the homogeneity of the material, and the repeatability of specimen preparation, test conditions, and measurements of the tension test parameters.

X1.3 Instrumental factors that can affect test results include: the stiffness, damping capacity, natural frequency, and mass of the tensile test machine, the accuracy of loading and the use of loads within the verified range for the machine, speed of loading, alignment of the test specimen with the applied load, parallelness of the grips, grip pressure, nature of the load control used, appropriateness and calibration of extensometers used. and so forth.

X1.4 Material factors that can affect test results include: representativeness and homogeneity of the test material. sampling scheme. and specimen preparation (surface finish. dimensional accuracy, fillets at the ends of the gage length. taper in the gage length. bent specimens. thread quality. and so forth).

X1.4.1 Some materials are very sensitive to the quality of the surface finish of the test specimen (see Note 11) and must be ground to a fine finish. or polished to obtain correct results.

X1.4.2 Test results for specimens with as-cast, as-rolled, as-forged, or other non-machined surface conditions can be affected by the nature of the surface (see Note 12).

X1.4.3 Test specimens taken from appendages to the part or component, such as prolongs or risers, or from separately produced castings (for example, keel blocks) may produce test results that are not representative of the part or component.

X1.4.4 Test specimen size can influence test results. For cylindrical specimens, changing the test specimen size generally has a negligible effect on the yield and tensile strength but may influence the yield point, if one is present, and will influence the elongation and reduction of area values. In general. increasing the specimen size reduces the % elongation and % reduction in area, although some studies have shown no effect, or the opposite effect. For rectangular tensile test specimens, increasing the width or thickness generally increases the % elongation and decreases the % reduction in area.

X1.4.5 Use of a taper in the gage length, up to the allowed limit, can result in lower elongation values. Reductions as much as 15 % have been reported for a 1 % taper.

X1.4.6 Some materials are highly strain-rate sensitive. Changes in the strain rate can affect the yield strength and elongation values, especially for strain-rate sensitive materials. In general, the yield strength and elongation will increase as the strain rate increases.

X1.4.7 Brittle materials require careful specimen preparation, high quality surface finishes, large fillets at the ends of the gage length, oversize threaded grip sections, and cannot tolerate punch or scribe marks as gage length indicators.

X1.4.8 Flattening of tubular products to permit testing does alter the material properties, generally nonuniformity, in the flattened region which may affect test results.

X1.5 Measurement errors that can affect test results include: verification of the test force, extensometers, micrometers, dividers. and other measurement devices, alignment and zeroing of chart recording devices, and so forth.

X1.5.1 Measurement of the dimensions of as-cast, as-rolled, as-forged. and other test specimens with non-machined surfaces may be imprecise due to the irregularity of the surface flatness.

X1.5.2 Materials with anisotropic flow characteristics may exhibit non-circular cross sections after fracture and measurement precision may be affected. as a result (see Note 24).

X1.5.3 The corners of rectangular test specimens are subject to constraint during deformation and the originally flat surfaces may be parabolic in shape after testing which will affect the precision of final cross-sectional area measurements (see Note 25).

X1.5.4 If any portion of the fracture occurs outside of the middle of the gage length, or in a punch or scribe mark within the gage length, the elongation and reduction of area values may not be representative of the material. Wire specimens that break at or within the grips may not produce test results representative of the material.

X1.5.5 Use of specimens with shouldered ends ("button-head" tensiles) will produce lower 0.02 % offset yield strength values than threaded specimens.

X1.6 Because standard reference materials with certified tensile property values are not available. it is not possible to rigorously define the bias of tension tests. However. by the use of carefully designed and controlled interlaboratory studies, a reasonable definition of the precision of tension test results can be obtained.

X1.6.1 An interlaboratory test program[8] was conducted where six specimens each, of six different materials were prepared and tested by each of six different laboratories. Tables 2.1 to 2.6 present the precision statistics, as defined in Practice E 691, for: tensile strength, 0.02 % yield strength, 0.2 % yield strength, % elongation in 5D, and % reduction in area. In each table, the first column lists the six materials tested, the second column lists the average of the average results obtained by the laboratories, the third and fifth columns list the repeatability and reproducibility standard deviations, the fourth and sixth columns list the coefficient of variation for these standard deviations, and the seventh

ınd eighth columns list the 95 % repeatability and reproducibility limits.

X1.6.2 The averages (below columns four and six in each able) of the coefficients of variation permit a relative omparison of the repeatability (within-laboratory precision) nd reproducibility (between-laboratory precision) of the ension test parameters. This shows that the ductility measurements exhibit less repeatability and reproducibility than ne strength measurements. The overall ranking from the ast to the most repeatable and reproducible is: % elongaon in 4D, % reduction in area, 0.02 % offset yield strength, .2 % offset yield strength, and tensile strength. Note that the rankings are in the same order for the repeatability and reproducibility average coefficients of variation and that the reproducibility (between-laboratory precision) is poorer than the repeatability (within-laboratory precision), as would be expected.

X1.6.3 No comments about bias can be made for the interlaboratory study due to the lack of certified test results for these specimens. However, examination of the test results showed that one laboratory consistently exhibited higher than average strength values and lower than average ductility values for most of the specimens. One other laboratory had consistently lower than average tensile strength results for all specimens.

TABLE X1.1 Precision Statistics—Tensile Strength, ksi

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| C-H19 | 25.66 | 0.63 | 2.45 | 0.63 | 2.45 | 1.76 | 1.76 |
| 2024-T351 | 71.26 | 0.88 | 1.24 | 0.96 | 1.34 | 2.47 | 2.68 |
| STM A105 | 86.57 | 0.60 | 0.70 | 1.27 | 1.46 | 1.68 | 3.55 |
| SI 316 | 100.75 | 0.39 | 0.39 | 1.21 | 1.20 | 1.09 | 3.39 |
| conel 600 | 99.48 | 0.42 | 0.43 | 0.72 | 0.72 | 1.19 | 2.02 |
| AE 51410 | 181.73 | 0.46 | 0.25 | 1.14 | 0.63 | 1.29 | 3.20 |
| | | Averages: | 0.91 | | 1.30 | | |

NOTE: X is the average of the cell averages, that is, the grand mean for the test parameter.
$s_r$ is the repeatability standard deviation (within-laboratory precision).
$s_r/X$ is the coefficient of variation in %.
$s_R$ is the reproducibility standard deviation (between-laboratory precision).
$s_R/X$ is the coefficient of variation, %.
r is the 95 % repeatability limits.
R is the 95 % reproducibility limits.

TABLE X1.2 Precision Statistics—0.02 % Yield Strength, ksi

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| -H19 | 16.17 | 0.65 | 3.99 | 1.19 | 7.36 | 1.81 | 3.33 |
| 24-T351 | 51.38 | 0.84 | 1.64 | 0.89 | 1.73 | 2.36 | 2.49 |
| TM A105 | 59.66 | 1.20 | 2.02 | 1.89 | 3.18 | 3.37 | 5.31 |
| I 316 | 48.62 | 2.39 | 4.91 | 4.61 | 9.49 | 6.68 | 12.91 |
| onel 600 | 38.74 | 0.46 | 1.18 | 0.76 | 1.96 | 1.28 | 2.13 |
| E 15410 | 104.90 | 2.40 | 2.29 | 3.17 | 3.02 | 6.73 | 8.88 |
| | | Averages: | 2.67 | | 4.46 | | |

TABLE X1.3 Precision Statistics—0.2 % Yield Strength, ksi

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| H19 | 22.98 | 0.47 | 2.06 | 0.48 | 2.07 | 1.33 | 1.33 |
| 4-T351 | 52.64 | 0.74 | 1.41 | 0.79 | 1.49 | 2.08 | 2.20 |
| M A105 | 58.36 | 0.83 | 1.42 | 1.44 | 2.47 | 2.31 | 4.03 |
| 316 | 69.63 | 0.94 | 1.35 | 2.83 | 4.07 | 2.63 | 7.93 |
| nel 600 | 38.91 | 0.36 | 0.93 | 0.85 | 2.18 | 1.01 | 2.37 |
| 51410 | 140.33 | 1.29 | 0.92 | 2.30 | 1.64 | 3.60 | 6.45 |
| | | Averages: | 1.35 | | 2.32 | | |

TABLE X1.4 Precision Statistics—% Elongation in 5D

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| EC-H19 | 14.61 | 0.59 | 4.03 | 0.66 | 4.52 | 1.65 | 1.85 |
| 2024-T351 | 18.04 | 0.64 | 3.57 | 1.72 | 9.53 | 1.81 | 4.81 |
| ASTM A105 | 25.63 | 0.77 | 2.99 | 1.30 | 5.06 | 2.15 | 3.63 |
| AISI 316 | 35.93 | 0.71 | 1.98 | 2.68 | 7.45 | 2.00 | 7.49 |
| Inconel 600 | 41.58 | 0.67 | 1.61 | 1.60 | 3.86 | 1.88 | 4.49 |
| SAE 51410 | 12.39 | 0.45 | 3.61 | 0.96 | 7.75 | 1.25 | 2.69 |
| | | Averages: | 2.97 | | 6.36 | | |

NOTE A1—Length of reduced section = 6D.

TABLE X1.5 Precision Statistics—% Reduction in Area

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| EC-H19 | 79.14 | 1.94 | 2.45 | 2.02 | 2.56 | 5.44 | 5.67 |
| 2024-T351 | 30.31 | 2.07 | 6.82 | 3.58 | 11.80 | 5.79 | 10.01 |
| ASTM A105 | 65.59 | 0.84 | 1.28 | 1.26 | 1.92 | 2.35 | 3.53 |
| AISI 316 | 71.49 | 0.99 | 1.39 | 1.61 | 2.25 | 2.78 | 4.50 |
| Inconel 600 | 59.34 | 0.67 | 1.14 | 0.70 | 1.18 | 1.89 | 1.97 |
| SAE 51410 | 50.49 | 1.86 | 3.69 | 3.95 | 7.81 | 5.21 | 11.05 |
| | | Averages: | 2.80 | | 4.59 | | |

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*This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.*

## APPENDIX

(Nonmandatory Information)

## X1. FACTORS AFFECTING TENSION TEST RESULTS

X1.1 The precision and bias of tension test strength and ductility measurements depend on strict adherence to the stated test procedure and are influenced by instrumental and material factors, specimen preparation, and measurement/testing errors.

X1.2 The consistency of agreement for repeated tests of the same material is dependent on the homogeneity of the material, and the repeatability of specimen preparation, test conditions, and measurements of the tension test parameters.

X1.3 Instrumental factors that can affect test results include: the stiffness, damping capacity, natural frequency, and mass of the tensile test machine, the accuracy of loading and the use of loads within the verified range for the machine, speed of loading, alignment of the test specimen with the applied load, parallelness of the grips, grip pressure, nature of the load control used, appropriateness and calibration of extensometers used, and so forth.

X1.4 Material factors that can affect test results include: representativeness and homogeneity of the test material, sampling scheme, and specimen preparation (surface finish, dimensional accuracy, fillets at the ends of the gage length, taper in the gage length, bent specimens, thread quality, and so forth).

X1.4.1 Some materials are very sensitive to the quality of the surface finish of the test specimen (see Note 11) and must be ground to a fine finish, or polished to obtain correct results.

X1.4.2 Test results for specimens with as-cast, as-rolled, as-forged, or other non-machined surface conditions can be affected by the nature of the surface (see Note 12).

X1.4.3 Test specimens taken from appendages to the part or component, such as prolongs or risers, or from separately produced castings (for example, keel blocks) may produce test results that are not representative of the part or component.

X1.4.4 Test specimen size can influence test results. For cylindrical specimens, changing the test specimen size generally has a negligible effect on the yield and tensile strength but may influence the yield point, if one is present, and will influence the elongation and reduction of area values. In general, increasing the specimen size reduces the % elongation and % reduction in area, although some studies have shown no effect, or the opposite effect. For rectangular tensile test specimens, increasing the width or thickness generally increases the % elongation and decreases the % reduction in area.

X1.4.5 Use of a taper in the gage length, up to the allowed % limit, can result in lower elongation values. Reductions of as much as 15 % have been reported for a 1 % taper.

X1.4.6 Some materials are highly strain-rate sensitive. Changes in the strain rate can affect the yield strength and elongation values, especially for strain-rate sensitive materials. In general, the yield strength and elongation will increase as the strain rate increases.

X1.4.7 Brittle materials require careful specimen preparation, high quality surface finishes, large fillets at the ends of the gage length, oversize threaded grip sections, and cannot tolerate punch or scribe marks as gage length indicators.

X1.4.8 Flattening of tubular products to permit testing does alter the material properties, generally nonuniformily, in the flattened region which may affect test results.

X1.5 Measurement errors that can affect test results include: verification of the test force, extensometers, micrometers, dividers, and other measurement devices, alignment and zeroing of chart recording devices, and so forth.

X1.5.1 Measurement of the dimensions of as-cast, as-rolled, as-forged, and other test specimens with non-machined surfaces may be imprecise due to the irregularity of the surface flatness.

X1.5.2 Materials with anisotropic flow characteristics may exhibit non-circular cross sections after fracture and measurement precision may be affected as a result (see Note 24).

X1.5.3 The corners of rectangular test specimens are subject to constraint during deformation and the originally flat surfaces may be parabolic in shape after testing which will affect the precision of final cross-sectional area measurements (see Note 25).

X1.5.4 If any portion of the fracture occurs outside of the middle of the gage length, or in a punch or scribe mark within the gage length, the elongation and reduction of area values may not be representative of the material. Wire specimens that break at or within the grips may not produce test results representative of the material.

X1.5.5 Use of specimens with shouldered ends ("button-head" tensiles) will produce lower 0.02 % offset yield strength values than threaded specimens.

X1.6 Because standard reference materials with certified tensile property values are not available, it is not possible to rigorously define the bias of tension tests. However, by the use of carefully designed and controlled interlaboratory studies, a reasonable definition of the precision of tension test results can be obtained.

X1.6.1 An interlaboratory test program[8] was conducted where six specimens each, of six different materials were prepared and tested by each of six different laboratories. Tables 2.1 to 2.6 present the precision statistics, as defined in Practice E 691, for: tensile strength, 0.02 % yield strength, 0.2 % yield strength, % elongation in 4D, and % reduction in area. In each table, the first column lists the six materials tested, the second column lists the average of the average results obtained by the laboratories, the third and fifth columns list the repeatability and reproducibility standard deviations, the fourth and sixth columns list the coefficients of variation for these standard deviations, and the seventh

and eighth columns list the 95 % repeatability and reproducibility limits.

X1.6.2 The averages (below columns four and six in each table) of the coefficients of variation permit a relative comparison of the repeatability (within-laboratory precision) and reproducibility (between-laboratory precision) of the tension test parameters. This shows that the ductility measurements exhibit less repeatability and reproducibility than the strength measurements. The overall ranking from the least to the most repeatable and reproducible is: % elongation in 5D, % reduction in area, 0.02 % offset yield strength, 0.2 % offset yield strength, and tensile strength. Note that the rankings are in the same order for the repeatability and reproducibility average coefficients of variation and that the reproducibility (between-laboratory precision) is poorer than the repeatability (within-laboratory precision), as would be expected.

X1.6.3 No comments about bias can be made for the interlaboratory study due to the lack of certified test results for these specimens. However, examination of the test results showed that one laboratory consistently exhibited higher than average strength values and lower than average ductility values for most of the specimens. One other laboratory had consistently lower than average tensile strength results for all specimens.

TABLE X1.1 Precision Statistics—Tensile Strength, MPa

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| C-H19 | 177.5 | 0.63 | 2.45 | 0.63 | 2.45 | 1.76 | 1.76 |
| 224-T351 | 492.9 | 0.88 | 1.24 | 0.96 | 1.34 | 2.47 | 2.68 |
| STM A105 | 598.8 | 0.60 | 0.70 | 1.27 | 1.46 | 1.68 | 3.55 |
| SI 316 | 696.9 | 0.39 | 0.39 | 1.21 | 1.20 | 1.09 | 3.39 |
| conel 600 | 688.1 | 0.42 | 0.43 | 0.72 | 0.72 | 1.19 | 2.02 |
| AE 51410 | 1257.0 | 0.46 | 0.25 | 1.14 | 0.63 | 1.29 | 3.20 |
| | | Averages: | 0.91 | | 1.30 | | |

NOTE: X is the average of the cell averages, that is, the grand mean for the test parameter.
$s_r$ is the repeatability standard deviation (within-laboratory precision).
$s_r/X$ is the coefficient of variation in %.
$s_R$ is the reproducibility standard deviation (between-laboratory precision).
$s_R/X$ is the coefficient of variation, %.
r is the 95 % repeatability limits.
R is the 95 % reproducibility limits.

TABLE X1.2 Precision Statistics—0.02 % Yield Strength, MPa

| Materia. | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| H19 | 111.8 | 0.65 | 3.99 | 1.19 | 7.36 | 1.81 | 3.33 |
| 4-T351 | 355.4 | 0.84 | 1.64 | 0.89 | 1.73 | 2.36 | 2.49 |
| M A105 | 412.7 | 1.20 | 2.02 | 1.89 | 3.18 | 3.37 | 5.31 |
| 316 | 336.3 | 2.39 | 4.91 | 4.61 | 9.49 | 6.68 | 12.91 |
| nel 600 | 268.0 | 0.46 | 1.18 | 0.76 | 1.95 | 1.28 | 2.13 |
| 15410 | 725.6 | 2.40 | 2.29 | 3.17 | 3.02 | 6.73 | 8.88 |
| | | Averages: | 2.67 | | 4.46 | | |

TABLE X1.3 Precision Statistics—0.2 % Yield Strength, MPa

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| 19 | 159.0 | 0.47 | 2.06 | 0.48 | 2.07 | 1.33 | 1.33 |
| T351 | 364.1 | 0.74 | 1.41 | 0.79 | 1.49 | 2.08 | 2.20 |
| A105 | 403.7 | 0.83 | 1.42 | 1.44 | 2.47 | 2.31 | 4.03 |
| 16 | 481.6 | 0.94 | 1.35 | 2.83 | 4.07 | 2.63 | 7.93 |
| 600 | 269.1 | 0.36 | 0.93 | 0.85 | 2.18 | 1.01 | 2.37 |
| 1410 | 970.7 | 1.29 | 0.92 | 2.30 | 1.64 | 3.60 | 6.45 |
| | | Averages: | 1.35 | | 2.32 | | |

TABLE X1.4 Precision Statistics—% Elongation in 4D

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| C-H19 | 17.45 | 0.64 | 3.69 | 0.92 | 5.30 | 1.80 | 2.59 |
| )24-T351 | 19.75 | 0.59 | 2.99 | 1.58 | 8.00 | 1.65 | 4.43 |
| STM A105 | 29.10 | 0.76 | 2.62 | 0.98 | 3.38 | 2.13 | 2.76 |
| SI 316 | 40.07 | 1.10 | 2.75 | 2.14 | 5.35 | 3.09 | 6.00 |
| conel 600 | 44.27 | 0.66 | 1.50 | 1.54 | 3.48 | 1.86 | 4.31 |
| AE 51410 | 14.48 | 0.48 | 3.29 | 0.99 | 6.83 | 1.34 | 2.77 |
| | | Averages: | 2.81 | | 5.39 | | |

NOTE A1—Length of reduced section = 6D.

TABLE X1.5 Precision Statistics—% Reduction in Area

| Material | X | $s_r$ | $s_r/X$, % | $s_R$ | $s_R/X$, % | r | R |
|---|---|---|---|---|---|---|---|
| C-H19 | 79.14 | 1.94 | 2.45 | 2.02 | 2.56 | 5.44 | 5.67 |
| 24-T351 | 30.31 | 2.07 | 6.82 | 3.58 | 11.80 | 5.79 | 10.01 |
| TM A105 | 65.59 | 0.84 | 1.28 | 1.26 | 1.92 | 2.35 | 3.53 |
| SI 316 | 71.49 | 0.99 | 1.39 | 1.61 | 2.25 | 2.78 | 4.50 |
| conel 600 | 59.34 | 0.67 | 1.14 | 0.70 | 1.18 | 1.89 | 1.97 |
| E 51410 | 50.49 | 1.86 | 3.69 | 3.95 | 7.81 | 5.21 | 11.05 |
| | | Averages: | 2.80 | | 4.59 | | |

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La máxima resistencia a la tensión y el módulo de elasticidad para cada polímero son:

| *Polímero* | *Resistencia a la tensión (psi)* | *Módulo de elasticidad (ksi)* | *Estructura* |
|---|---|---|---|
| Polietileno BD | 3000 | 40 | Altamente ramificada, amorfa con meros simétricos |
| Polietileno AD | 5500 | 180 | Amorfa con meros simétricos pero escasa ramificación |
| Polipropileno | 6000 | 220 | Amorfa con pequeños grupos laterales de metilo |
| Poliestireno | 8000 | 450 | Amorfa con grupos laterales de benceno |
| Cloruro de polivinilo | 9000 | 600 | Amorfa con grandes átomos de cloruro como grupos laterales |

Se puede concluir que

(a) La ramificación, que reduce la densidad y la compactación de las cadenas, reduce las propiedades mecánicas del polietileno.

(b) Añadiendo átomos o grupos diferentes del hidrógeno a la cadena, se incrementan la resistencia y la rigidez. El grupo metilo en el polipropileno proporciona alguna mejoría, el anillo de benceno del estireno proporciona mejores propiedades y el átomo de cloruro en el cloruro de polivinilo proporciona una gran mejora en las propiedades mecánicas.

| *Polímero* | *Resistencia a la tensión (psi)* | *Elongación (%)* | *Módulo de elasticidad (ksi)* |
|---|---|---|---|
| Termoplásticos por adición lineales | 3000-12,000 | 5-800 | 40-600 |
| Termoplásticos por condensación lineales | 8000-17,000 | 10-300 | 250-600 |
| Polímeros termoestables | 4000-15,000 | 0-6 | 500-1,600 |

Los polímeros por adición lineales tienen la menor resistencia y rigidez pero la mayor ductilidad. Los termoestables tienen la mayor resistencia y rigidez pero son frágiles. La mayoría de los termoplásticos por condensación lineales tiene propiedades intermedias; su estructura molecular es normalmente más compleja que la de los polímeros por adición, pero no están ligados en forma cruzada como los termoestables.

# PROPIEDADES DE LOS PLASTICOS *

| Propiedades | Método de ensayo de la ASTM | Compuesto de fenol-formaldehído | | | | Compuesto de urea formaldehído, en relleno de alfacelulosa (Beetle, Plaskon) † | Compuesto de molde de formaldehído de melamina-relleno de alfacelulosa (Melmac, Plaskon) † | Compuesto de celulosa | | Compuesto de molde de acetato de cloruro de vinilo rígido (Vinilita) † | Compuesto de molde de poliéster, relleno de fibra de vidrio (Plaskon) † | Compuesto de resina metacrilato de metilo (Lucita, Plexiglas) † | Compuesto de molde de poliestireno (Bakelita, Catalina) † | Resina epóxica reforzada con tela de vidrio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Moldeado (Bakelita, Durez, Durite) † | | | Fundido sin relleno (Catalin, Marblette) † | | | Acetato de celulosa (Plastacele, Lumarith) † | Nitrato de celulosa (Celuloide de Nitrea y Pyralin) † | | | | | |
| | | Sin relleno | Relleno de lámina de madera | Relleno de fibra macerada | | | | | | | | | | |
| Peso específico | D 792 | 1.25-1.30 | 1.32-1.55 | 1.36-1.43 | 1.30-1.32 | 1.47-1.52 | 1.47-1.52 | 1.27-1.34 | 1.35-1.40 | 1.34-1.45 | 1.90 | 1.18-1.19 | 1.05-1.06 | 1.8 |
| Resistencia a la tracción, lbs/pig² | D 638, D 651 | 7-8 | 6.5-8.5 | 3.5-9 | 6-9 | 7-13 | 7-13 | 1.9-5.5 | 7-8 | 7.2-9 | 5-9 | 7.5-10 | 5-9 | 50 |
| Elongación, % | D 638 | 1.0-1.5 | 0.4-0.8 | 0.37-0.57 | 1.5-2.0 | 0.5-1.0 | 0.6-0.9 | 6-50 | 40-45 | ..... | ..... | 2-10 | 1.0-3.6 | |
| Módulo de elasticidad, $10^4$ lbs/pig² | D 638 | 7.5-10 | 8-12 | 9-13 | 4-5 | 15 | 13 | 0.86-4.0 | 1.9-22 | 3.5-4.1 | 16-20 | 4.5 | 4-6 | 250 |
| Resistencia a la compresión, lbs/pig² | D 695 | 10-30 | 20-30 | 15-30 | 12-15 | 25-35 | 25-13 | 13-36 | 22-35 | 9.9-11.3 | 20-25 | 12-18 | 11.5-16 | 60 |
| Resistencia a la flexión, lbs/pig² | D 790 | 12-15 | 8.5-12 | 8.5-15 | 11-17 | 16-16 | 10-16 | 2-16 | 9-11 | 12.6-14.5 | 14-17 | 13-17 | 8-16 | 70 |
| Resistencia al impacto, lb-pie/pig de ranura, ensayo Izod | D 256 | 0.20-0.30 | 0.21-0.60 | 0.75-8.0 | 0.25-0.30 | 0.25-0.35 | 0.24-0.35 | 0.4-5.2 | 5.0-7.0 | 0.4-0.7 | 12-24 | 0.4-0.5 | 0.25-0.50 | 20 |
| Dureza de Rockwell | D 785 | M124-M125 | M100-M120 | M85-M120 | M93-M120 | M115-M120 | M110-M125 | R50-R125 | R95-R115 | ..... | ..... | M85-M105 | M65-M90 | |
| Expansión térmica, pig/pig × $10^4$ × °C | D 696 | 2.5-6.0 | 3.0-4.5 | 1-4 | 6-8 | 2-7 | 4.0 | 8-16 | 8-12 | 6.9-18.5 | 1.0-3.0 | 9 | 6-8 | 9 |
| Temperatura térmica de distorsión, °F | D 648 | 240-260 | 260-340 | 250-300 | 165-175 | 270-280 | 400 | 115-235 | 140-160 | 140-155 | 400 | 190-195 | 180-210 | 250 |
| Constante dieléctrica, 60 ciclos | D 150 | 5-8.5 | 5-9 | 6.5-15 | 6.5-7.5 | 7.0-9.5 | 7.9-9.5 | 3.5-7.5 | 7.0-7.5 | 3.2-3.3 | 5.2-6.0 | 3.5-4.5 | 2.4-2.6 | |
| Factor de disipación, 60 ciclos | D 150 | 0.06-0.10 | 0.05-0.30 | 0.08-0.45 | 0.10-0.15 | 0.01 | 0.03-0.08 | 0.01-0.06 | 0.08-0.12 | 0.01 | 0.02 | 0.04-0.06 | 0.000 | |
| Absorción de agua, 24 hr, ⅛ pig de grueso, % | D 570 | 0.1-0.2 | 0.3-1.0 | 0.01-1.75 | 0.3-0.4 | 0.4-0.8 | 0.1-0.6 | 1.7-6.5 | 1.0-2.0 | 0.07-0.08 | 0.15-0.20 | 0.3-0.4 | 0.03-0.05 | |
| Calidad de moldeo | ..... | Regulares | Excelente | Buenas y regulares | ..... | Excelente | Excelente | Excelente | Bueno | Excelente | ..... | Excelente | Excelente | |
| Calidades de maquinado | ..... | Regulares a buenas | Regulares a buenas | Regulares a buenas | Excelentes | Regulares | Regular | Bueno | Excelente | Bueno | Regular | Excelente | Ligeramente bueno | |
| Claridad | ..... | Transparente, translúcido | Opaco | Opaco | Transparente a opaco | Translúcido a opaco | Translúcido | Transparente a opaco | Transparente a opaco | Transparente a opaco | Opaco | Transparente | Transparente | |
| Posibilidades de color | ..... | Oscuro | Limitado | Limitado | Ilimitado | Ilimitado | Ilimitado | Ilimitado | Ilimitado | Ilimitado | Limitado | Ilimitado | Ilimitado | |

**TABLA 12-5** Grupos funcionales para varios polímeros termoestables

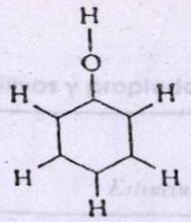
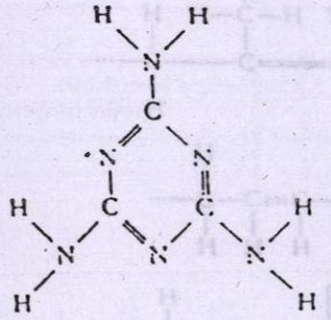
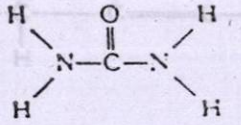
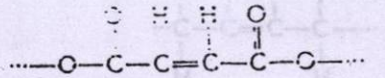
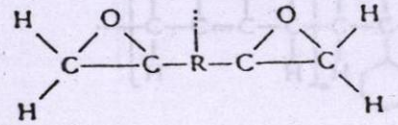
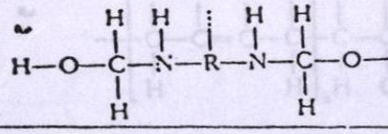
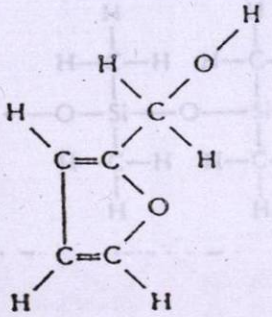
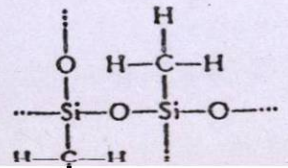
| *Polímero* | *Estructura* | *Resistencia a la tensión (psi)* | *Elongación (%)* | *Módulo de elasticidad (ksi)* | *Densidad (g/cm³)* |
|---|---|---|---|---|---|
| Fenólicos |  | 5,000–9,000 | 0–2 | 400–1300 | 1.27 |
| Aminas |  Melamina | 5,000–10,000 | 0–1 | 1000–1600 | 1.50 |
| |  Urea | | | | |
| Poliésteres |  | 6,000–13,000 | 2–3 | 300–650 | 1.25 |
| Epóxicos |  | 4,000–15,000 | 0–6 | 400–500 | 1.25 |
| Uretanos |  | 5,000–10,000 | 3–6 | | 1.30 |
| Furanos |  | 3,000–4,500 | | 1580 | 1.75 |
| Silicones |  | 3,000–4,000 | 0 | 1200 | 1.55 |

TABLA 12-4 Unidades repetitivas y propiedades de algunos elastómeros

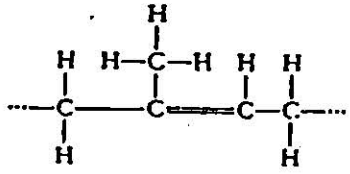
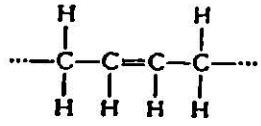
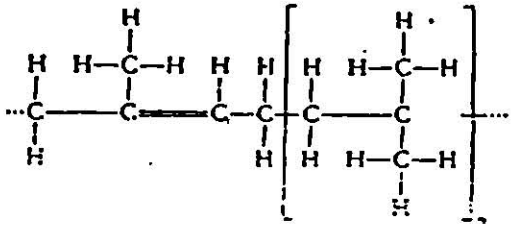
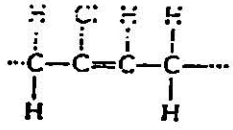
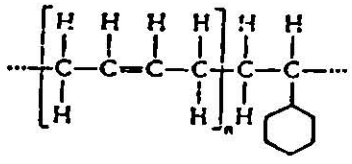
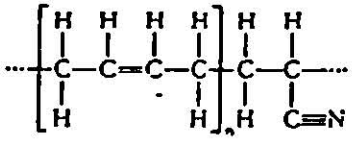
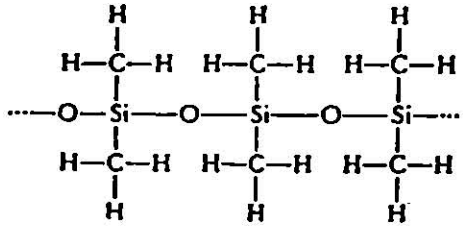
| *Polímero* | *Estructura* | *Resistencia a la tensión, (psi)* | *Elongación (%)* | *Densidad (g/cm³)* |
|---|---|---|---|---|
| Poliisopreno |  | 3000 | 800 | 0.93 |
| Polibutadieno |  | 3500 | | 0.94 |
| Polibutileno |  | 4000 | 350 | 0.92 |
| Policloropreno (neopreno) |  | 3500 | 800 | 1.24 |
| Butadieno-estireno (caucho BS o SBR) |  | 600–3000 | 600–2000 | 1.0 |
| Butadieno-acrilonitrilo |  | 700 | 400 | 1.0 |
| Silicón |  | 350–1000 | 100–700 | 1.5 |

TABLA 12-3 (continuación)

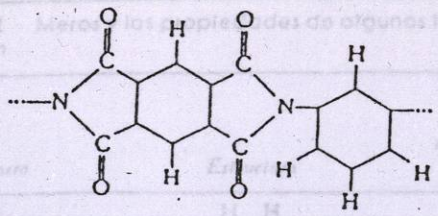
| Polímero | Estructura | Resistencia a la tensión (psi) | Elongación (%) | Módulo de elasticidad (ksi) | Densidad (g/cm³) |
|---|---|---|---|---|---|
| Poliimida |  | 11,000–17,000 | 8–10 | 300 | 1.39 |

TABLA 12-3 Unidades repetitivas y propiedades para termoplásticos típicos que tienen estructuras de cadena complicadas

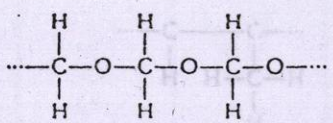
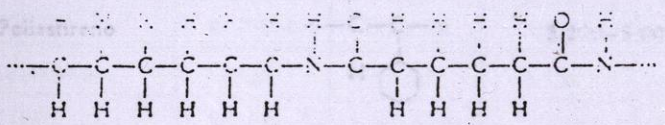
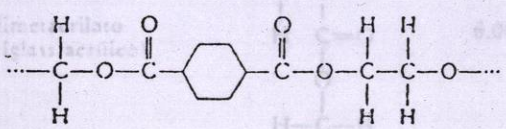
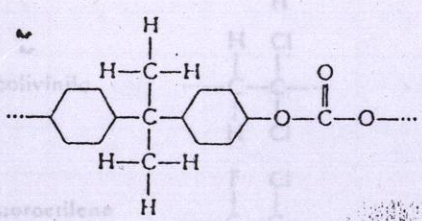
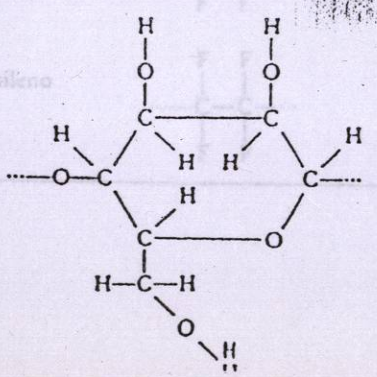
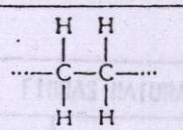
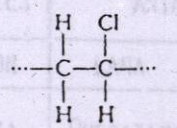
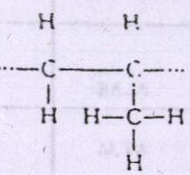
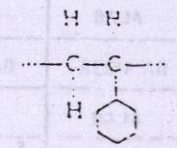
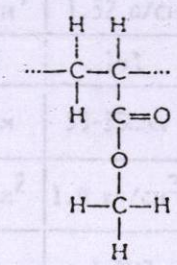
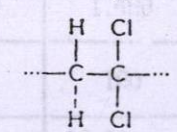
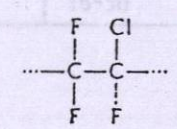
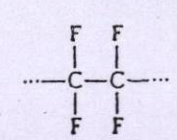
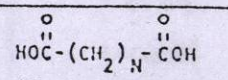
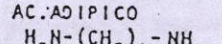
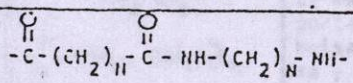
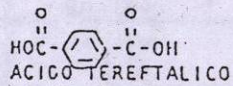
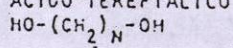
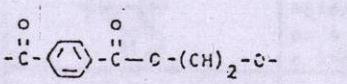
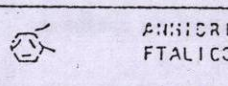
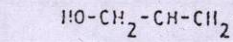
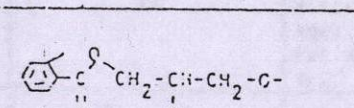
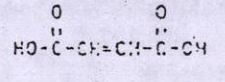
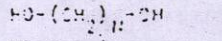
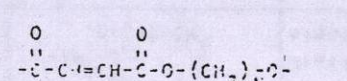
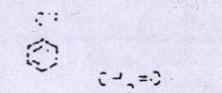
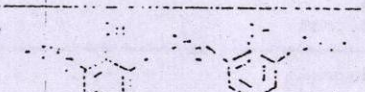
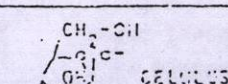
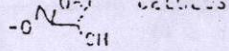
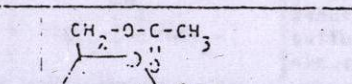
| Polímero | Estructura | Resistencia a la tensión (psi) | Elongación (%) | Módulo de elasticidad (ksi) | Densidad (g/cm³) |
|---|---|---|---|---|---|
| Poliéter (acetal) |  | 9,500–12,000 | 25–75 | 520 | 1.42 |
| Poliamida (nylon) |  | 11,000–12,000 | 60–300 | 400–500 | 1.14 |
| Poliéster (ducrón) |  | 8,000–10,500 | 50–300 | 400–600 | 1.36 |
| Policarbonato |  | 9,000–11,000 | 110–130 | 300–400 | 1.2 |
| Celulosa |  | 2,000–8,000 | 5–50 | 200–250 | 1.30 |

TABLA 12-2 Meros y las propiedades de algunos termoplásticos producidos mediante polimerización por adición

| *Polímero* | *Estructura* | *Resistencia a la tensión (psi)* | *Elongación (%)* | *Módulo de elasticidad (ksi)* | *Densidad (g/cm³)* |
|---|---|---|---|---|---|
| Polietileno |  | | | | |
| baja densidad (BD) | | 600–3,000 | 50–800 | 15–40 | 0.92 |
| alta densidad (AD) | | 3,000–5,500 | 15–130 | 60–180 | 0.96 |
| Cloruro de polivinilideno |  | 5,000–9,000 | 2–100 | 300–600 | 1.40 |
| Polipropileno |  | 4,000–6,000 | 10–700 | 160–220 | 0.90 |
| Poliestireno |  | 3,200–5,000 | 1–60 | 350–450 | 1.05 |
| Polimetilmetacrilato (Plexiglass acrílico) |  | 6,000–12,000 | 2–5 | 350–450 | 1.22 |
| Cloruro de polivinilo |  | 3,500–5,000 | 160–240 | 50–80 | 1.15 |
| Policlorotrifluoroetileno |  | 4,500–6,000 | 80–250 | 150–300 | 2.15 |
| Politetrafluoroetileno (teflón) |  | 2,000–7,000 | 100–400 | 60–80 | 2.17 |

| PROPIEDAD DE LA FIBRA | FIBRAS NATURALES | | | FIBRAS ARTIFICIALES (ORGANICAS) | | | FIBRAS ARTIFICIALES INORGANICAS |
|---|---|---|---|---|---|---|---|
| | VEGETALES | ANIMALES | | CONDENSACION | | ADICION | |
| NOMBRE DE FIBRA | ALGODON | LANA | SEDA | NILON | TERYLENE | POLIETILENO | VIDRIO |
| UNIDAD MONOME | CELULOSA | QUERATINA | FIBROINA Y SERICÍNA | AMIDA | ESTER | ETILENO | $SiO_2$ |
| RESISTENCIA: | | | | | | | |
| a) ÁLCALIS | ALTA | BAJA | BAJA | ALTA | REGULAR | BUENA | MALA |
| b) SOLVENTES ORGÁNICOS | ALTA | ALTA | ALTA | REGULAR | REGULAR | REGULAR | BUENA |
| c) ÁCIDOS | BAJA | BAJA | BAJA | BAJA | REGULAR | BUENA | BUENA |
| d) HONGOS | REGULAR | REGULAR | BAJA | ALTA | ALTA | ALTA | ALTA |
| e) INSECTOS | BAJA | BAJA | BAJA | ALTA | ALTA | ALTA | ALTA |
| DENSIDAD | 1.54 g/cm$^3$ | 1.32 g/cm$^3$ | 1.22 | 1.14 g/cm$^3$ | 1.18 | 0.9-0.92g/cm$^3$ | 2.5-2.7 g/cm$^3$ |
| ABSORBENCIA $H_2O$ | 7-8.5% | 14% | 30% | 4% | CASI NULO | NULA | |
| LONGITUD DE 1 FIBRA | 12-65mm | 35-350mm | MÁS DE 1000 m POR CAPULLO | 25-125mm | | | |
| MAXIMO PESO QUE SOPORTA 1 HILO | 4.2 kg/cm$^2$ | 1.4 kg/cm$^2$ | 3.70kg/cm$^2$ | 50-70kg/cm$^2$ | | | |
| RESISTENCIA A LA TRACCION (kg/cm$^2$) | 4.200 | 1.400 | 4.90 | 5.0 | 4.900 | .400 | 21.00 |
| TEMPERATURA MAX. DE TRABAJO °C | 100 | 100 | 200 | 210 | 220 | 70 | 350 |
| DIAMETRO | 20 | 16-50 | 8-15 | | | | |

| EJEMPLO | MONOMEROS | P O L I M E R O (UNIDAD MONOMERICA) | USOS |
|---|---|---|---|
| POLIAMIDAS (nylon) |  ACIDO ADIPICO  HEXAMETILEN DIAMINA |  | Fibras y objetos moldeados. |
| POLIESTERES (dacrón, mylar, fortrel) |  ACIDO TEREFTALICO  SI N=2 ETILENGLICOL |  | Polímeros lineales, fibras, cintas magnéticas. |
| POLIESTERES |  ANHIDRICO FTALICO  GLICERINA |  | Pinturas, poliesteres de cadena cruzada. |
| POLIESTERES |   |  | Cadena cruzada con estireno y peróxido: resina-fibra de vidrio. |
| RESINA FENOL FORMALDEHIDO (BAKELITA) |  FORMALDEHIDO FENOL |  | Ácidos, alcoholes, barnices. |
| ACETATO DE CELULOSA |  CELULOSA  ACIDO ACETICO |  | Película fotográfica. |

POLIMEROS POR CONDENSACION.

| EJEMPLO | MONOMEROS | (UNIDAD MONOMERICA) POLIMERO | USOS |
|---|---|---|---|
| POLIETILENO | $CH_2=CH_2$<br>ETILENO | $-CH_2-CH_2-$<br>$[-CH_2-CH_2-]_n$ | El más común e importante polimero bolsas, aislamiento y botellas moldeadas. |
| POLIPROPILENO | $CH_2=CH$<br>$\vert$<br>$CH_3$<br>PROPILENO | $-CH_2-CH-$<br>$\vert$<br>$CH_3$ | Fibras para alfombras interiores y exteriores. |
| POLIESTIRENO | $CH_2=CH$<br>ESTIRENO | $-CH_2-CH-$ | Moldeo de objetos para uso doméstico e industrial. |
| POLICLORURO DE VINILO<br>PVC | $CH_2=CH$<br>$\vert$<br>$Cl$<br>CLORURO DE VINILO | $-CH_2-CH-$<br>$\vert$<br>$Cl$ | Recubrimiento de pisos acetatos de discos, tubos para agua, envases y botellas transparente. |
| POLITETRA FLUORURO DE ETILENO (TEFLON PTFE) | $F_2C=CF_2$<br>TETRAFLUORO ETILENO | $-CF_2-CF_2-$ | Caras inastillables resistente a películas químicas. |
| POLIMETACRILATO DE METILO | $O=C-O-CH_3$<br>$CH_2=C$<br>$CH_3$<br>METIL-METACRILATO. | $O=C-O-CH_3$<br>$-CH_2-C-$<br>$CH_3$ | Vidrio irrompible y pinturas latex. |
| POLIACRILO NITRICO<br>Orlon, orilan, Orestán. | [illegible] | [illegible] | [illegible] |
| POLI-ACETATO DE VINILO | $CH_2=CH$<br>$O-C-CH_3$<br>$\Vert$<br>$O$<br>ACETATO DE VINILO | $-CH_2-CH-$<br>$\vert$<br>$O-C-CH_3$<br>$\Vert$<br>$O$ | Adhesivos, pinturas latex, capas textiles y gomas de mascar. |
| HULE NATURAL | $CH_3$<br>$\vert$<br>$CH_2=C-CH=CH_2$<br>CIS-ISOPRENO | $CH_3$<br>$\vert$<br>$-CH_2-C=CH-CH_2-$ | El polimero con cadenas cruzadas de sulfuro por (vulcanización). |
| POLICLOROPRENO (NEOPRENO) | $Cl$<br>$\vert$<br>$CH_2=C-CH=CH_2$<br>CLOROPRENO | $Cl$<br>$\vert$<br>$-CH_2-C=CH-CH_2-$ | Con cadenas cruzadas de Zn O es resistente a aceites y gasolinas. |
| ESTIRENO-BUTADIENO (SBR) | $CH=CH_2$ ESTIRENO<br>BUTADIENO<br>$CH_2=CH-CH=CH_2$ | $-CH_2-CH-CH_2-CH=CH-CH_2-$<br>BUNA S | Con cadenas cruzadas de peróxido; es el mas común hule usado para llantas, contiene 75% butadieno. |

POLIMEROS POR ADICION.

## TABLA B.3. PROPIEDADES MECANICAS DE LAS ALEACIONES LIGERAS NO FERROSAS*

| Aleación | Composición aproximada, porcentaje | Resistencia a la cedencia por tensión,† lb/plg² | Resistencia a la tensión, lb/plg² | Módulo de elasticidad en tensión, $10^6$ lb/plg² | Porciento de elongación en 2 plg | Resistencia al corte, lb/plg² | Número de dureza de Rockwell | Límite de fatiga para flexiones revertidas, lb/plg² | Peso, lb/plg³ |
|---|---|---|---|---|---|---|---|---|---|
| Aleación de aluminio 2024: | | | | | | | | | |
| Temple O | Aluminio 93; cobre 4.5; magnesio 1.5; manganeso 0.6 | 11 000 | 27 000 | 10.6 | 20 | 18 000 | H00 | 13 000 | 0.100 |
| Temple T36 | | 57 000 | 72 000 | 10.6 | 13 | 42 000 | B80 | 18 000 | 0.100 |
| Aleación de aluminio 2014: | | | | | | | | | |
| Temple O | Aluminio 93; cobre 4.4; sílice 0.8; manganeso 0.8; magnesio 0.4 | 14 000 | 27 000 | 10.6 | 18 | 18 000 | H92 | 13 000 | 0.102 |
| Temple T6 | | 60 000 | 70 000 | 10.6 | 13 | 42 000 | B33 | 18 000 | 0.102 |
| Aleación de aluminio 5052: | | | | | | | | | |
| Temple O | Aluminio 97; magnesio 2.5; cromo 0.25 | 13 000 | 28 000 | 10.0 | 30 | 18 000 | H82 | 16 000 | 0.096 |
| Temple H38 | | 37 000 | 42 000 | 10.0 | 8 | 24 000 | E85 | 20 000 | 0.096 |
| Aleación de aluminio 5456: | | | | | | | | | |
| Temple O | Aluminio 94; magnesio 5.0; maganeso 0.7; cobre 0.15; cromo 0.15 | 23 000 | 45 000 | .... | 24 | 28 000 | ... | ..... | 0.092 |
| Temple H321 | | 37 000 | 51 000 | .... | 16 | 30 000 | ... | ..... | 0.092 |
| Aleación de aluminio 7075: | | | | | | | | | |
| Temple O | Aleación 90; cinc 5.5; cobre 1.5; magnesio 2.5; cromo 0.3 | 15 000 | 33 000 | .... | 17 | 22 000 | E63 | | |
| Temple T6 | | 73 000 | 83 000 | .... | 11 | 48 000 | B90 | 23 000 | |
| Aleación de magnesio AM100A. | | | | | | | | | |
| Fundición, condición F | Magnesio 90; aluminio 10; manganeso 0.1 | 12 000 | 22 000 | 6.5 | 2 | 18 000 | E64 | 10 000 | 0.066 |
| Fundición, condición T61 | | 22 000 | 40 000 | 6.5 | 1 | 21 000 | E80 | 10 000 | 0.066 |
| Aleación de magnesio AZ63A: | | | | | | | | | |
| Fundición, condición F | Magnesio 91; aluminio 6; cinc 3; manganeso 0.2 | 14 000 | 29 000 | 6.5 | 6 | 18 000 | E59 | 11 000 | 0.066 |
| Fundición, condición T6 | | 19 000 | 40 000 | 6.5 | 5 | 20 000 | E83 | 11 000 | 0.066 |

Propiedades elásticas de materiales representativos, a temperatura ordinaria

| Material | Módulo Young $E$, $10^{10}$ N/m²† | Relación de Poisson, $\nu$ | Rigidez específica $E/\rho$, $10^6$ N · m/kg‡ |
|---|---|---|---|
| Grafito | 100 | | 5 000 |
| Cristales de $Al_2O_3$ (zafiro) | | | |
| $[10\bar{1}0]$ | 230 | | 586 |
| $[11\bar{2}0]$ | 125 | | 310 |
| [0001] | 48 | | 120 |
| Boro | 45 | 0.21 | 190 |
| Carburo sinterizado (WC) | 65 | 0.20 | 46 |
| Vítreo-cerámico | 10 | 0.25 | 39 |
| Vidrio de sílice | 8 | 0.24 | 32 |
| Aleaciones de aluminio | 7 | 0.33 | 26 |
| Acero | 20 | 0.28 | 25 |
| Tungsteno | 41 | 0.29 | 21 |
| Madera (típica): | | | |
| longitudinal§ | 1 | ~0.04 | 16 |
| radial | 0.07 | ~0.3 | 1 |
| tangencial | 0.06 | ~0.5 | 1 |
| Aleaciones de cobre | 12 | 0.35 | 13 |
| Nilón (*nylon*) | 0.3 | 0.48 | 3 |
| Polietileno | 0.04 | 0.3 | 0.4 |

† Para convertir N/m² en kgf/cm², multipliquese por $1.020 \times 10^{-5}$ y en lb/pulg², por $1.450 \times 10^{-4}$.

‡ Para convertir N · m/kg en kgf · m/kg, multipliquese por 9.80 y en lb · pulg/lb$_{masa}$, por 4.01.

TABLA 6-3 Relación entre el módulo de elasticidad y la temperatura de fusión de los metales

| *Metal* | *Temperatura de fusión (°C)* | *Módulo de elasticidad (psi)* |
|---|---|---|
| Pb | 327 | $2.0 \times 10^5$ |
| Mg | 650 | $6.5 \times 10^5$ |
| Al | 660 | $10.0 \times 10^5$ |
| Ag | 962 | $10.3 \times 10^6$ |
| Au | 1064 | $11.3 \times 10^6$ |
| Cu | 1085 | $18.1 \times 10^6$ |
| Ni | 1453 | $29.9 \times 10^6$ |
| Fe | 1538 | $30.0 \times 10^6$ |
| Mo | 2610 | $43.4 \times 10^6$ |
| W | 3410 | $58.5 \times 10^6$ |

**TABLA 13-2** Propiedades de algunos materiales reforzados con fibras

| *Material* | *Densidad* ($g/cm^3$) | *Resistencia a la tensión* (ksi) | *Módulo de elasticidad* ($\times 10^6$ psi) | *Temperatura de fusión* (°C) | *Módulo específico* ($\times 10^9$ plg) | *Resistencia específica* ($\times 10^6$ plg) |
|---|---|---|---|---|---|---|
| Vidrio E | 2.55 | 500 | 10.5 | <1725 | 11.4 | 5.6 |
| Vidrio S | 2.50 | 650 | 12.6 | <1725 | 14.0 | 7.2 |
| $SiO_2$ | 2.19 | 850 | 10.5 | 1728 | 13.3 | 10.8 |
| $Al_2O_3$ | 3.15 | 300 | 23.0 | 2015 | 21.9 | 2.6 |
| $ZrO_2$ | 4.84 | 300 | 50 | 2677 | 28.6 | 1.7 |
| Grafito HS (alta resistencia) | 1.50 | 400 | 40 | 3700 | 74.2 | 7.4 |
| Grafito HM (alto módulo) | 1.50 | 270 | 77 | 3700 | 143 | 5.0 |
| BN | 1.90 | 200 | 13 | 2730 | 18.8 | 2.9 |
| Boro | 2.36 | 500 | 55 | 2030 | 64.7 | 4.7 |
| $B_4C$ | 2.36 | 330 | 70 | 2450 | 82.4 | 3.9 |
| SiC | 4.09 | 300 | 70 | 2700 | 47.3 | 2.0 |
| $TiB_2$ | 4.48 | 13 | 74 | 2980 | 45.3 | 0.1 |
| Be | 1.85 | 185 | 44 | 1277 | 77.5 | 2.3 |
| W | 19.4 | 580 | 59 | 3410 | 3.5 | 0.3 |
| Mo | 10.2 | 320 | 32 | 2610 | 14.1 | 0.9 |
| Kevlar | 1.44 | 525 | 18 | | 54.7 | 10.1 |
| *Whiskers* | | | | | | |
| de $Al_2O_3$ | 3.96 | 3000 | 62 | 1982 | 43.4 | 21.0 |
| de BeO | 2.83 | 1900 | 50 | 2550 | 48.5 | 18.5 |
| de $B_4C$ | 2.52 | 2000 | 70 | 2450 | 76.9 | 22.1 |
| de SiC | 3.18 | 3000 | 70 | 2700 | 60.8 | 26.2 |
| de $Si_3N_4$ | 3.18 | 2000 | 55 | | 47.8 | 17.5 |
| de grafito | 1.66 | 3000 | 102 | 3700 | 170 | 50.2 |
| de Cr | 7.2 | 1290 | 35 | 1890 | 13.4 | 4.9 |
| de Cu | 8.92 | 427 | 18 | 1083 | 5.6 | 1.3 |

Adaptado de L. J. Broutman, "Mechanical Properties of Fiber Reinforced Plastics", *Composite Engineering Laminates*, ed. G. H. Denz, The M.I.T. Press, 1969

## TABLA D.1. RESISTENCIA DE LA MADERA SECADA A LA INTEMPERIE [a,b]

| Nombre comercial | Peso específico | Peso, lb/pie³ | Flexión estática [c] | | | Flexión por impacto, [e] altura de caída que causa la falla, golpe de 50 lb, plg | Compresión paralela al grano [d] | | Compresión perpendicular del grano, esfuerzo en el límite proporcional, lb/plg² [f] | Corte paralelo al grano, resistencia máxima, lb/plg² |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Esfuerzo en las fibras en el límite proporcional, lb/plg² | Módulo de | | | Esfuerzo en el límite proporcional, lb/plg² | Resistencia máxima, lb/plg² | | |
| | | | | Ruptura, lb/plg² | Elasticidad, 1 000 lb/plg² | | | | | |
| Fresno de Oregón..... | 0.55 | 34 | 7 000 | 12 700 | 1 360 | 33 | 4 100 | 6 040 | 1 540 | 1 790 |
| Cedar, rojo occidental.... | 0.33 | 21 | 5 300 | 7 700 | 1 120 | 17 | 4 360 | 5 020 | 610 | 860 |
| Douglas fir (de la costa). | 0.48 | 30 | 8 100 | 11 700 | 1 920 | 30 | 6 450 | 7 420 | 910 | 1 140 |
| Hemlock, occidental..... | 0.42 | 26 | 6 800 | 10 100 | 1 490 | 26 | 5 340 | 6 210 | 680 | 1 170 |
| Jícore, verdadero..... | 0.73 | 46 | 10 900 | 19 700 | 2 180 | 75 | ..... | 8 970 | 2 310 | 2 140 |
| Locust, negro..... | 0.69 | 43 | 12 800 | 19 400 | 2 050 | 57 | 6 800 | 10 180 | 2 260 | 2 480 |
| Maple, rojo..... | 0.54 | 34 | 8 700 | 13 400 | 1 640 | 32 | 4 650 | 6 540 | 1 240 | 1 850 |
| Roble, blanco..... | 0.67 | 42 | 7 900 | 13 900 | 1 620 | 39 | 4 350 | 7 040 | 1 410 | 1 890 |
| Pino de ponderosa..... | 0.40 | 25 | 6 300 | 9 200 | 1 260 | 17 | 4 000 | 5 270 | 740 | 1 160 |
| Pino de hoja larga..... | 0.58 | 36 | 9 300 | 14 700 | 1 990 | 34 | 6 130 | 8 440 | 1 190 | 1 500 |
| Madera roja (virgen).... | 0.40 | 25 | 6 900 | 10 000 | 1 340 | 19 | 4 560 | 6 150 | 860 | 940 |
| Abeto de Sitka..... | 0.40 | 25 | 6 700 | 10 200 | 1 570 | 25 | 4 780 | 5 610 | 710 | 1 130 |

[a] *Wood Handbook* (Manual de la Madera), Forest Products Laboratory (Laboratorio de Productos Forestales), U.S. Department of Agriculture (Departamento de Agricultura de los Estados Unidos), 1955.

[b] Todas las probetas son de madera limpia de grano recto con un contenido de humedad de 12%.

[c] Probeta de 2 × 2 × 30 plg sobre claro de 28 plg.

[d] Probeta de 2 × 2 × 8 plg, 6 plg longitud.

[e] Probeta de 2 × 2 × 6 plg, 4 plg bajo carga.

[f] 4 plg² bajo carga. Resistencia al corte transversal al grano, aproximadamente 5 veces el equivalente de la paralela al grano.

PARTE 2 — CERÁMICAS (Tomados de medios numerosos)

| Material | Gravedad específica | Conductividad térmica en $\frac{\text{cal·cm}}{\text{°C·cm}^2\text{·seg}}$ a 20°C* | Expansión térmica en plg/plg/°C a 20°C† | Resistividad eléctrica en ohm·cm a 20°C‡ | Módulo de elasticidad promedio, lb/plg² a 20°C |
|---|---|---|---|---|---|
| $Al_2O_3$ | 3.8 | 0.07 | $5 \times 10^{-6}$ | — | $50 \times 10^6$ |
| Tabique | | | | | |
| Edificio | 2.3(±) | 0.0015 | $5 \times 10^{-6}$ | — | — |
| Arcilla fuego | 2.1 | 0.002 | $2.5 \times 10^{-6}$ | $1.4 \times 10^8$ | — |
| Grafito | 1.5 | — | $3 \times 10^{-6}$ | — | — |
| Pavimento | 2.3 | — | $2 \times 10^{-6}$ | — | — |
| Silice | 1.75 | 0.002 | — | $1.2 \times 10^8$ | — |
| Concreto | 2.4(±) | 0.0025 | $7 \times 10^{-6}$ | — | $2 \times 10^6$ |
| Vidrio | | | | | |
| Plancha | 2.5 | 0.0018 | $5 \times 10^{-6}$ | $10^{14}$ | — |
| Borosilicato | 2.4 | 0.0025 | $1.5 \times 10^{-6}$ | — | $10 \times 10^6$ |
| Silice | 2.2 | 0.003 | $0.3 \times 10^{-6}$ | $10^{20}$ | $10 \times 10^6$ |
| Vycor | 2.2 | 0.003 | $0.35 \times 10^{-6}$ | — | — |
| Lana | 0.05 | 0.0006 | — | — | — |
| Grafito (bulk) | 1.9 | — | $3 \times 10^{-6}$ | $10^{-3}$ | $1 \times 10^6$ |
| MgO | 3.6 | — | $5 \times 10^{-6}$ | $10^5$ (2000°F) | $30 \times 10^6$ |
| Cuarzo ($SiO_2$) | 2.65 | 0.03 | $7 \times 10^{-6}$ | — | $45 \times 10^6$ |
| SiC | 3.17 | 0.029 | $2.3 \times 10^{-6}$ | 2.5 (2000°F) | — |
| TiC | 4.5 | 0.07 | $4 \times 10^{-6}$ | $50 \times 10^{-6}$ | $50 \times 10^6$ |

PARTE 3 — MATERIALES ORGÁNICOS (Tomados de números medios).

| Material | Gravedad específica | Conductividad térmica en $\frac{\text{cal·cm}}{\text{°C·cm}^2\text{·seg}}$ a 20°C* | Expansión térmica en plg/plg/°C a 20°C† | Resistividad eléctrica en ohm·cm a 20°C‡ | Módulo de elasticidad promedio, lb/plg² a 20°C |
|---|---|---|---|---|---|
| Melamina-formaldehido | 1.5 | 0.0007 | $15 \times 10^{-6}$ | $10^{13}$ | $1.3 \times 10^6$ |
| Fenol-formaldehido | 1.3 | 0.0004 | $40 \times 10^{-6}$ | $10^{12}$ | $0.5 \times 10^6$ |
| Urea-formaldehido | 1.5 | 0.0007 | $15 \times 10^{-6}$ | $10^{12}$ | $1.5 \times 10^6$ |
| Hules (sintéticos) | 1.5 | 0.0003 | — | — | 500–10,000 |
| Hule (vulcanizado) | 1.2 | 0.0003 | $45 \times 10^{-6}$ | $10^{14}$ | $0.5 \times 10^6$ |
| Polietileno | 0.9 | 0.0008 | $100 \times 10^{-6}$ | $10^{19}$ | — |
| Poliestireno | 1.05 | 0.0002 | $35 \times 10^{-6}$ | $10^{18}$ | $0.4 \times 10^6$ |
| Cloruro de polivinilideno | 1.7 | 0.0003 | $105 \times 10^{-6}$ | $10^{13}$ | $0.05 \times 10^6$ |
| Politetrafluoroetileno | 2.2 | 0.0005 | $55 \times 10^{-6}$ | $10^{16}$ | — |
| Metacrilato de polimetilo | 1.2 | 0.0005 | $50 \times 10^{-6}$ | $10^{16}$ | $0.5 \times 10^6$ |
| Nylon | 1.15 | 0.0006 | $55 \times 10^{-6}$ | $10^{14}$ | $0.4 \times 10^6$ |

plicar por 0.806 para tener Btu·plg/°F·pie²·seg. † Multiplicar por 1.8 para tener cm/cm/°C. ‡ Dividir entre 2.54 para tener ohm·plg.

**ABLA 10-8 Designaciones de grado de endurecimiento para aleaciones de cobre**

Hxx—trabajada en frío. (xx indica el grado de trabajo en frío.)

| | | Reducción porcentual en espesor o diámetro |
|---|---|---|
| H01 | ¼ dura | 10.9 |
| H02 | ½ dura | 20.7 |
| H03 | ¾ dura | 29.4 |
| H04 | dura | 37.1 |
| H06 | extradura | 50.1 |
| H08 | de resorte duro | 60.5 |
| H10 | de resorte extra | 68.6 |
| H12 | de resorte especial | 75.1 |
| H14 | de superresorte | 80.3 |

Mxx—tal como se manufactura. (xx se refiere al tipo de proceso de fabricación.)
Oxx—recocida. (xx designa el método de recocido.)
OSxxx—recocida para producir un tamaño particular de grano. (xxx se refiere al diámetro del grano en $10^{-3}$ mm. Por tanto, OS025 señalaría un diámetro de grano de 0.025 mm.)
TB00—tratada por solución.
TF00—endurecida por envejecimiento.
TQxx—templada y revenida. (xx da detalles del tratamiento térmico.)

**TABLA 10-9 Composiciones, propiedades y aplicaciones de algunas aleaciones de níquel y cobalto**

| *Material* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* | *Aplicaciones* |
|---|---|---|---|---|
| Ni puro (99.9% Ni) | | | | |
| Recocido | 50,000 | 16,000 | 45 | Resistencia a la corrosión |
| Trabajado en frío | 95,000 | 90,000 | 4 | |
| Monel 400 (Ni-31.5% Cu) | 78,000 | 39,000 | 37 | Válvulas, bombas cambiadores de calor |
| Superaleaciones de Ni | | | | |
| Hastelloy B-2 (Ni-28% Mo) | 130,000 | 60,000 | 61 | Resistencia a la corrosión |
| MAR-M246 (Ni-10% Co-9% Cr-10% W + Ti, Al, Ta) | 140,000 | 125,000 | 5 | Motores de reacción |
| DS-Ni ($Ni-2\% ThO_2$) | 71,000 | 48,000 | 14 | Turbinas de gas |
| Superaleaciones de Fe-Ni | | | | |
| Incoloy 800 (Ni-46% Fe-21% Cr) | 89,000 | 41,000 | 37 | Cambiadores de calor |
| Superaleaciones de Co | | | | |
| Haynes 25 (50% Co-20% Cr-15% W-10% Ni) | 135,000 | 65,000 | 60 | Motores de reacción |
| Estelita 6B (60% Co-30% Cr-4.5% W) | 177,000 | 103,000 | 4 | Resistencia al desgaste por abrasión |

Datos de *Metals Handbook*, Vol. 3, 9a. ed., American Society for Metals, 1980.

**TABLA 10-1** Efecto de los mecanismos de endurecimiento en el aluminio y en las aleaciones de aluminio

| *Material* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* | *Esfuerzo de fluencia (aleación) / Esfuerzo de fluencia (puro)* |
|---|---|---|---|---|
| Aluminio puro recocido (99.999% Al) | 6,500 | 2,500 | 60 | |
| Aluminio puro comercial (recocido, 99% Al) | 13,000 | 5,000 | 45 | 2.0 |
| Endurecido por solución sólida (1.2% Mn) | 16,000 | 6,000 | 35 | 2.4 |
| Aluminio puro trabajado en frío un 75% | 24,000 | 22,000 | 15 | 8.8 |
| Endurecido por dispersión (5% Mg) | 42,000 | 22,000 | 35 | 8.8 |
| Endurecido por envejecimiento (5.6% Zn-2.5% Mg) | 83,000 | 73,000 | 11 | 29.2 |

Datos modificados de *Metals Handbook*, Vol. 2, 9a. ed., American Society for Metals, 1979.

**TABLA 10-7** Propiedades de aleaciones típicas de cobre obtenidas por diferentes mecanismos de endurecimiento

| *Material* | *Designación de grado de endurecimiento* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* | *Mecanismo de endurecimiento* |
|---|---|---|---|---|---|
| Cobre puro, recocido | | 30,300 | 4,800 | 60 | |
| Cobre comercialmente puro, recocido para engrosar el tamaño de grano | O5050 | 32,000 | 10,000 | 55 | |
| Cobre comercialmente puro, recocido para afinar el tamaño de grano | O5025 | 34,000 | 11,000 | 55 | Tamaño de grano |
| Cobre comercialmente puro, trabajado en frío | H10 | 57,000 | 53,000 | 4 | Endurecimiento por deformación |
| Cu-35% Zn recocido | OS050 | 47,000 | 15,000 | 62 | Solución sólida |
| Cu-30% Ni tal como se fabrica | M20 | 55,000 | 20,000 | 45 | |
| Cu-10% Sn recocido | O5035 | 66,000 | 28,000 | 68 | |
| Cu-35% Zn trabajado en frío | H10 | 98,000 | 63,000 | 3 | Solución sólida + Endurecimiento por deformación |
| Cu-30% Ni trabajado en frío | H80 | 84,000 | 79,000 | 3 | |
| Cu-2% Be endurecido por envejecimiento | TF00 | 190,000 | 175,000 | 4 | Endurecimiento por envejecimiento |
| Cu-Al templado y revenido | TQ50 | 110,000 | 60,000 | 5 | Reacción martensítica |
| Manganeso bronce fundido | F | 71,000 | 28,000 | 30 | Reacción eutectoide |

Datos de *Metal. Handbook*, Vol. 2, 9a. ed., American Society for Metals, 1979.

**TABLA 10-2** Sistema de designación para las aleaciones de aluminio

| | | |
|---|---|---|
| **Aleaciones para forja** | | |
| 1xxx | Alum. comercialmente puro (>99% Al) | No envejecido |
| 2xxx | Al-Cu | Endurecible por envejecimiento |
| 3xxx | Al-Mo | No envejecido |
| 4xxx | Al-Si y Al-Mg-Si | Endurecible por envejecimiento si hay magnesio presente |
| 5xxx | Al-Mg | No envejecido |
| 6xxx | Al-Mg-Si | Endurecible por envejecimiento |
| 7xxx | Al-Mg-Zn | Endurecible por envejecimiento |
| **Aleaciones fundidas** | | |
| 1xx.x | Alum. comercialmente puro | No envejecido |
| 2xx.x | Al-Cu | Endurecible por envejecimiento |
| 3xx.x | Al-Si-Cu ó Al-Mg-Si | Algunas son endurecibles por envejecimiento |
| 4xx.x | Al-Si | No envejecido |
| 5xx.x | Al-Mg | No envejecido |
| 7xx.x | Al-Mg-Zn | Endurecible por envejecimiento |
| 8xx.x | Al-Sn | Endurecible por envejecimiento |

**TABLA 10-3** Propiedades de algunas aleaciones de aluminio

| *Aleación* | | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* | *Comentarios* |
|---|---|---|---|---|---|
| **Aleaciones para forja no tratables térmicamente** | | | | | |
| 1100-O | >99% Al | 13,000 | 5,000 | 40 | Componentes eléctricos, hojas |
| 1100-H18 | | 24,000 | 22,000 | 10 | metálicas finas ("papel"), |
| 3003-O | 1.2% Mn | 16,000 | 6,000 | 35 | resistencia a la corrosión. |
| 3003-H18 | | 29,000 | 27,000 | 7 | Latas para bebidas, aplicacio |
| 4043-O | 5.2% Si | 21,000 | 10,000 | 22 | arquitectónicas. |
| 5056-O | 5% Mg | 42,000 | 22,000 | 35 | Metal de relleno en soldadura |
| 5056-H18 | | 60,000 | 50,000 | 15 | recipientes, componentes marinos. |
| **Aleaciones para forja tratables térmicamente** | | | | | |
| 2024-O | 4.4% Cu | 27,000 | 11,000 | 20 | |
| 2024-T4 | | 68,000 | 47,000 | 20 | |
| 4032-T6 | 12% Si-1% Mg | 55,000 | 46,000 | 9 | Transportes, aeronáutica, |
| 6061-T6 | 1% Mg-0.6% Si | 45,000 | 40,000 | 15 | astronáutica y otras |
| 7075-T6 | 5.6% Zn-2.5% Mg | 83,000 | 73,000 | 11 | aplicaciones de alta resisten |
| **Aleaciones para fundición** | | | | | |
| 295-T6 | 4.5% Cu-0.8% Si | 36,000 | 24,000 | 5 | Arena |
| 319-F | 6% Si-3.5% Cu | 27,000 | 18,000 | 2 | Arena |
| | | 34,000 | 19,000 | 2.5 | Molde permanente |
| 356-T6 | 7% Si-0.3% Mg | 33,000 | 24,000 | 3.5 | Arena |
| | | 38,000 | 27,000 | 5 | Molde permanente |
| 380-F | 8.5% Si-3.5% Cu | 46,000 | 23,000 | 3.5 | Molde permanente |
| 390-F | 17% Si-4.5% Cu-0.6% Mg | 41,000 | 35,000 | 1 | Coquilla |
| 443-F | 5.2% Si | 19,000 | 8,000 | 8 | Arena |
| | | 23,000 | 9,000 | 10 | Molde permanente |
| | | 33,000 | 16,000 | 9 | Coquilla |
| 713-T5 | 7.5% Zn-0.7% Cu-0.35% Mg | 30,000 | 22,000 | 4 | Arena |

Datos modificados de *Metals Handbook*, Vol. 2, 9a. ed., American Society for Metals, 1979.

**TABLA 10-10** Propiedades de algunas aleaciones de titanio

| *Material* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* |
|---|---|---|---|
| Titanio comercialmente puro | | | |
| 99.5% Ti | 35,000 | 25,000 | 24 |
| 99.0% Ti | 80,000 | 70,000 | 15 |
| Aleaciones Ti alfa | | | |
| 5% Al-2.5% Sn | 125,000 | 113,000 | 15 |
| Aleaciones Ti beta | | | |
| 13% V-11% Cr-3% Al | 187,000 | 176,000 | 5 |
| Aleaciones Ti casi alfa | | | |
| 8% Al-1% Mo-1% V | 140,000 | 120,000 | 14 |
| 6% Al-4% Zr-2% Sn-2% Mo | 146,000 | 144,000 | 3 |
| Aleaciones Ti alfa-beta | | | |
| 8% Mn | 140,000 | 125,000 | 15 |
| 6% Al-4% V | 150,000 | 140,000 | 8 |

Datos de *Metals Handbook*, Vol. 3, 9a. ed., American Society for Metals, 1980.

**TABLA 10-11** Propiedades de metales refractarios

| *Metal* | *Temperatura de fusión (°C)* | *Densidad (g/cm³)* | *Temperatura ambiente* | | | *T* = 1000°C | |
|---|---|---|---|---|---|---|---|
| | | | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* |
| Nb | 2470 | 8.66 | 45,000 | 20,000 | 25 | 17,000 | 8,000 |
| Mo | 2610 | 10.22 | 120,000 | 80,000 | 10 | 50,000 | 30,000 |
| Ta | 2996 | 16.6 | 50,000 | 35,000 | 35 | 27,000 | 24,000 |
| W | 3410 | 19.25 | 300,000 | 220,000 | 3 | 66,000 | 15,000 |

PARTE 1 — METALES (Tomados de medios numerosos)

| Material | Densidad | Conductividad térmica cal·cm / °C·cm²·seg a 20°C* | Expansión térmica plg/plg/°F a 20°C† | Resistividad eléctrica en ohm·cm a 20°C‡ | Módulo de elasticidad promedio, lb/plg² a 20°C |
|---|---|---|---|---|---|
| Aluminio (99.9+) | 2.7 | 0.53 | $12.5 \times 10^{-6}$ | $2.9 \times 10^{-6}$ | $10 \times 10^6$ |
| Aleaciones Al | 2.7(+) | 0.4(±) | $12 \times 10^{-6}$ | $3.5 \times 10^{-6}$(+) | $10 \times 10^6$ |
| Latón (70Cu-30Zn) | 8.5 | 0.3 | $11 \times 10^{-6}$ | $6.2 \times 10^{-6}$ | $16 \times 10^6$ |
| Bronce (95Cu-5Sn) | 8.8 | 0.2 | $10 \times 10^{-6}$ | $9.6 \times 10^{-6}$ | $16 \times 10^6$ |
| Cobre (99.9+) | 8.9 | 0.95 | $9 \times 10^{-6}$ | $1.7 \times 10^{-6}$ | $16 \times 10^6$ |
| Hierro (99.9+) | 7.87 | 0.18 | $6.53 \times 10^{-6}$ | $9.7 \times 10^{-6}$ | $29 \times 10^6$ |
| Plomo (99+) | 11.34 | 0.08 | $16 \times 10^{-6}$ | $20.65 \times 10^{-6}$ | $2 \times 10^6$ |
| Magnesio (99+) | 1.74 | 0.38 | $14 \times 10^{-6}$ | $4.5 \times 10^{-6}$ | $6.5 \times 10^6$ |
| Monel (70Ni–30Cu) | 8.8 | 0.06 | $8 \times 10^{-6}$ | $48.2 \times 10^{-6}$ | $26 \times 10^6$ |
| Plata (sterling) | 10.4 | 1.0 | $10 \times 10^{-6}$ | $1.8 \times 10^{-6}$ | $11 \times 10^6$ |

## TABLA B.1. PROPIEDADES MECANICAS DE LOS METALES NO FERROSOS *

| Metal | Resistencia a la cedencia por tensión, lb/plg² † | Resistencia a la tensión, lb/plg² | Módulo de elasticidad en tensión, $10^6$ lb/plg² | Elongación en 2 plg, porcentaje | No. de dureza de Brinell | Peso, lb/plg³ |
|---|---|---|---|---|---|---|
| Cobre, 0.25 plg grueso: | | | | | | |
| Recocidos grano de 0.05 mm | 10 000 | 32 000 | 16 | 45 | 47 | 0.320 |
| Duro | 45 000 | 50 000 | 16 | 12 | 105 | 0.320 |
| Níquel: | | | | | | |
| Rolado en caliente | 25 000 | 75 000 | 30 | 45 | 110 | 0.310 |
| Rolado duro | 120 000 | 140 000 | 30 | 2 | ... | 0.319 |
| Cinc: | | | | | | |
| Vaciado | ..... | 6 000 | 11 | 1 | ... | 0.260 |
| Lámina rolada dura | 5 000 | 24 000 | 12 | 35 | ... | 0.260 |
| Aluminio: | | | | | | |
| Vaciado en arena, 1100-F | 6 000 | 11 000 | 9 | 22 | ... | 0.097 |
| Lámina recocida, 1 100-0 | 5 000 | 13 000 | 10 | 35 | 23 | 0.097 |
| Lámina dura, 1100-H18 | 21 000 | 24 000 | 10 | 5 | 44 | 0.097 |
| Magnesio: | | | | | | |
| Vaciado | 600 | 13 000 | 6 | 6 | 30 | 0.063 |
| Extruida | 1 200 | 28 000 | 6 | 8 | 35 | 0.063 |
| Rolado | 3 000 | 25 000 | 6 | 4 | 40 | 0.063 |

## TABLA B.2. PROPIEDADES MECANICAS DE LAS ALEACIONES PESADAS NO FERROSAS *

| Aleación | Composición aproximada, porcentajes | Resistencia a la cedencia por tensión, † lb/plg² | Resistencia a la tensión lb/plg² | Módulo de elasticidad por tensión, $10^6$ lb/plg² | Porciento de elongación en 2 plg | Resistencia al corte, lb/plg² | Número de dureza Rockwell | Peso, lb/plg³ |
|---|---|---|---|---|---|---|---|---|
| Latón para corte libre: | | | | | | | | |
| Recocido | Cobre 61.5; cinc 35.5; plomo 3 | 18 000 | 49 000 | 12 | 53 | 30 000 | F68 | 0.30 |
| ¼ duro 15% de reducción | | 45 000 | 56 000 | 12 | 20 | 33 000 | B62 | 0.30 |
| Medio duro, 25% de reducción | | 52 000 | 68 000 | 14 | 18 | 38 000 | B80 | 0.30 |
| Latón con alto contenido de plomo (0.04 plg de grueso): | | | | | | | | |
| Recocido, grano de 0.050 mm | Cobre 65; cinc 33; plomo 2 | 15 000 | 47 000 | 12 | 55 | 33 000 | F66 | 0.30 |
| Extraduro | | 62 000 | 85 000 | 15 | 5 | 45 000 | B87 | 0.30 |
| Latón rojo (0.04 plg de grueso): | | | | | | | | |
| Recocido, grano de 0.070 mm | Cobre 85; cinc 15 | 10 000 | 39 000 | 12 | 48 | 31 000 | F66 | 0.31 |
| de grueso extra duro | | 61 000 | 78 000 | 15 | 4 | 44 000 | B83 | 0.31 |
| Bronce al aluminio: | | | | | | | | |
| Vaciado en arena | Cobre 89; aluminio 8; hierro 3 | 28 000 | 75 000 | ... | 40 | ..... | ..... | 0.30 |
| Extruido | | 37 500 | 82 000 | 18 | 25 | ..... | ..... | 0.30 |
| Cobre al berilio: | | | | | | | | |
| A (solución recocida) | Cobre 97.9; berilio 1.9; níquel 0.2 | ..... | 70 000 ± | 18 | 35 | ..... | B60 ± | 0.32 |
| H.T. endurecido | | 150 000 | 200 000 | 18 | 2 | ..... | C42 | 0.32 |
| Bronce al manganeso (A): | | | | | | | | |
| Recocido, suave, duro 15% de reducción | Cobre 58.5; cinc 39; hierro 1.4; estaño 1; manganeso 0.1 | 30 000 | 65 000 | 13 | 35 | 42 000 | B65 | 0.30 |
| | | 60 000 | 82 000 | 15 | 25 | 47 000 | B90 | 0.30 |
| Bronce al fósforo, 5% (A): | | | | | | | | |
| Recocido, grano de 0.035 mm | Cobre 95; estaño 5 | 22 000 | 49 000 | 13 | 57 | ..... | B33 | 0.32 |
| Extraduro, grano de 0.015 mm | | 92 000 | 94 000 | 17 | 5 | ..... | B94 | 0.32 |
| Cuproníquel, 30%: | | | | | | | | |
| Recocido a 1 400°F. Laminado en frío, 50% de reducción | Cobre 70; níquel 30 | 20 000 | 55 000 | 22 | 45 | ..... | B37 | 0.32 |
| | | 78 000 | 85 000 | 22 | 15 | ..... | B81 | 0.32 |

**TABLA 10-14** Composiciones y propiedades de algunos aceros inoxidables

| *Acero* | *% C* | *% Cr* | *% Ni* | *Otros* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *Elongación (%)* |
|---|---|---|---|---|---|---|---|
| Austenítico | | | | | | | |
| 201 | 0.15 | 16–18 | 3.5–5.5 | 5.5–7.5% Mn | 95,000 | 45,000 | 40 |
| 304 | 0.08 | 18–20 | 8.0–10.5 | | 75,000 | 30,000 | 30 |
| 304L | 0.03 | 18–20 | 8–12 | | 75,000 | 30,000 | 30 |
| 321 | 0.08 | 17–19 | 9–12 | Ti (5 × % C) | 85,000 | 35,000 | 55 |
| 347 | 0.08 | 17–19 | 9–13 | Nb (10 × % C) | 90,000 | 35,000 | 50 |
| Ferrítico | | | | | | | |
| 430 | 0.12 | 16–18 | | | 65,000 | 30,000 | 22 |
| 442 | 0.12 | 18–23 | | | 75,000 | 40,000 | 20 |
| Martensítico | | | | | | | |
| 416 | 0.15 | 12–14 | | 0.60% Mo | 180,000 | 140,000 | 18 |
| 431 | 0.20 | 15–17 | 1.25–2.30 | | 200,000 | 150,000 | 16 |
| 440C | 0.95–1.2 | 16–18 | | 0.75% Mo | 285,000 | 275,000 | ? |
| Endurecimiento por precipitación | | | | | | | |
| 17-4 | 0.07 | 16–18 | 3–5 | 0.15–0.45% Nb | 190,000 | 170,000 | 10 |
| 17-7 | 0.09 | 16–18 | 6.5–7.8 | 0.75–1.25% Al | 240,000 | 230,000 | 6 |

Modificado a partir de *Metals Handbook*, Vol. 3, 9a. ed., American Society for Metals, 1980.

**TABLA 10-15** Propiedades representativas de fundiciones típicas

| *Clasificación* | *Resistencia a la tensión (psi)* | *Esfuerzo de fluencia (psi)* | *% A* | |
|---|---|---|---|---|
| Clase 20, fundición gris | 12,000–40,000 | | <1 | CE > 4.2% |
| Clase 40, fundición gris | 28,000–54,000 | | <1 | CE < 4.0% |
| 35018, fundición maleable | 53,000 | 35,000 | 18 | Ferrita |
| 90001, fundición maleable | 105,000 | 90,000 | 1 | Martensita revenida |
| 60-40-18, fundición dúctil | 60,000 | 40,000 | 18 | Ferrita |
| 120-90-02, fundición dúctil | 120,000 | 90,000 | 2 | Martensita revenida |
| Fundición de grafito grado B compactada | 50,000 | 40,000 | 1 | Ferrita + perlita |

## TABLA A. 2. PROPIEDADES MECANICAS DEL HIERRO Y DEL ACERO*

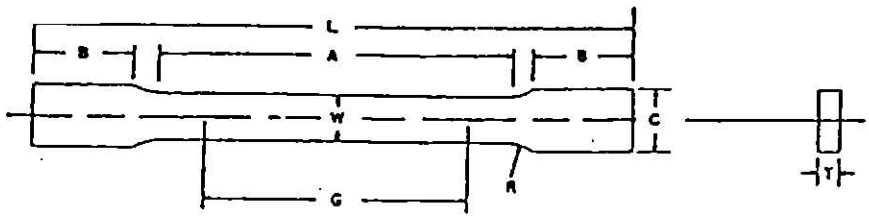
| Material | Resistencia a la tensión, kips/plg² | | Resistencia a la cedencia por compresión† kips/plg² | Resistencia al corte por torsión, kips/plg² | | Módulo de elasticidad, $10^6$ lb/plg² | | Porciento de elongación en 2 plg | Número de dureza de Brinell | Módulo de tenacidad lb-plg/plg³ | Límite de duración, flexión invertida, kips/plg² |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resis. a la cedencia† | Ultima | | Resis. a la cedencia† | Ultima | Tensión | Corte | | | | |
| Fundición gris | ... | 20 | 35 | ... | 37 | 15 | 6 | 1 | 130 | 80 | 11 |
| Fundición blanca | ... | 60 | 100 | ... | 60 | 20 | 8 | ... | 400 | | |
| Fundición al níquel, 1.5% de níquel | ... | 45 | 60 | ... | ... | 20 | 8 | 1 | 200 | | |
| Hierro maleable | 33 | 50 | 33 | 19 | 48 | 25 | 10 | 14 | 120 | ..... | 20 |
| Hierro en lingotes, recocido, 0.02% de carbono | 21 | 42 | 21 | 15 | 30 | 30 | 12 | 45 | 70 | ..... | 26 |
| Hierro forjado, 0.10% de carbono | 30 | 50 | 30 | 18 | 35 | 27 | 10 | 30 | 100 | 14 000 | 25 |
| Acero, 0.20% de carbono: | | | | | | | | | | | |
| Rolado en caliente | 40 | 60 | 40 | 24 | 45 | 30 | 12 | 35 | 120 | 16 300 | 31 |
| Rolado en frío | 60 | 80 | 60 | 36 | 60 | 30 | 12 | 15 | 160 | 12 000 | 40 |
| Fundiciones recocidas | 35 | 60 | 35 | 21 | 45 | 30 | 12 | 25 | 130 | | |
| Acero, 0.40% de carbono: | | | | | | | | | | | |
| Rolado en caliente | 42 | 70 | 42 | 25 | 55 | 30 | 12 | 25 | 135 | | |
| Tratamiento térmico para grano fino | 60 | 90 | 60 | 36 | 75 | 30 | 12 | 25 | 190 | | |
| Fundiciones recocidas | 35 | 65 | 35 | 21 | 55 | 30 | 12 | 15 | 130 | | |
| Acero, 0.60% de carbono: | | | | | | | | | | | |
| Rolado en caliente | 63 | 100 | 63 | 37 | 80 | 30 | 12 | 15 | 200 | 12 300 | 50 |
| Con tratamiento térmico para grano fino | 78 | 120 | 78 | 47 | 100 | 30 | 12 | 15 | 235 | 15 000 | 55 |
| Acero, 0.80% de carbono: | | | | | | | | | | | |
| Rolado en caliente | 73 | 120 | 73 | 44 | 105 | 30 | 12 | 10 | 240 | | |
| Apagado en aceite, no laminado | 125 | 150 | 125 | 75 | 150 | 30 | 12 | 2 | 360 | | |
| Acero 1.00% de carbono: | | | | | | | | | | | |
| Rolado en caliente | 83 | 135 | 83 | 50 | 115 | 30 | 12 | 10 | 260 | 11 000 | 60 |
| Apagado en aceite, no laminado | 140 | 220 | 140 | 84 | 185 | 30 | 12 | 1 | 400 | 2 000 | 100 |
| Acero al níquel, 3.5% de níquel, 0.40% de carbono, máxima dureza para maquinabilidad | 130 | 170 | 130 | 90 | 140 | 30 | 12 | 12 | 350 | 14 000 | 75 |
| Acero al silicomanganeso, 1.95% de silicio, 0.70% de Mn, templado para resortes | 130 | 174 | 130 | 73 | 115 | 30 | 12 | 1 | 360 | 21 000 | |

*Nota:* La mayoría de los aceros dependen tanto del tratamiento térmico como de su composición para desarrollar propiedades mecánicas pa: ulares.

## TABLA A.3. REQUERIMIENTOS PARA FUNDICIONES DE HIERRO GRIS *

| Clase No. | Resistencia a la tensión lb/plg² | Carga de ruptura por flexión al centro, mínima, libras | | |
|---|---|---|---|---|
| | | 0.875 plg de diám, claro de 12 plg | 1.2 plg de diám, claro de 18 plg | 2.0 plg de diám, claro de 24 plg |
| 20 | 20 000 | 900 | 1 800 | 6 000 |
| 25 | 25 000 | 1 025 | 2 000 | 6 800 |
| 30 | 30 000 | 1 150 | 2 200 | 7 600 |
| 35 | 35 000 | 1 275 | 2 400 | 8 300 |
| 40 | 40 000 | 1 400 | 2 600 | 9 100 |
| 50 | 50 000 | 1 675 | 3 000 | 10 300 |
| 60 | 60 000 | 1 925 | 3 400 | 12 500 |

* Basado en ASTM A 48.




| Dimensions | Standard Specimens | | Subsize Specimen |
|---|---|---|---|
| | Plate-Type, 1½-in. Wide | Sheet-Type, ½-in. Wide | ¼-in. Wide |
| | in. | in. | in. |
| *G*—Gage length (Notes 1 and 2) | 8.00 ± 0.01 | 2.000 ± 0.005 | 1.000 ± 0.003 |
| *W*—Width (Notes 3 and 4) | 1½ + ⅛, −¼ | 0.500 ± 0.010 | 0.250 ± 0.005 |
| *T*—Thickness (Note 5) | | thickness of material | |
| *R*—Radius of fillet, min (Note 6) | 1 | ½ | ¼ |
| *L*—Over-all length, min (Notes 2 and 7) | 18 | 8 | 4 |
| *A*—Length of reduced section, min | 9 | 2¼ | 1¼ |
| *B*—Length of grip section, min (Note 8) | 3 | 2 | 1¼ |
| *C*—Width of grip section, approximate (Notes 4 and 9) | 2 | ¾ | ⅜ |

NOTE 1—For the 1½-in. wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of nine or more punch marks 1 in. apart, or one or more pairs of punch marks 8 in. apart may be used.

NOTE 2—When elongation measurements of 1½-in. wide specimens are not required, a minimum length of reduced section (*A*) of 2¼ in. may be used with all other dimensions similar to those of the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.004, 0.002 or 0.001 in., respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 0.015, 0.005, or 0.003 in., respectively, larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used.

NOTE 5—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 1½-in. wide specimens shall be ⅝ in. Maximum thickness of ½-in. and ¼-in. wide specimens shall be ¾ in. and ½ in., respectively.

NOTE 6—For the 1½-in. wide specimen, a ½-in. minimum radius at the ends of the reduced section is permitted for steel specimens under 100 000 psi in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—To aid in obtaining axial loading during testing of ¼-in. wide specimens, the over-all length should be as large as the material will permit, up to 8.00 in.

NOTE 8—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of ½-in. wide specimens is over ⅜ in., longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 9—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 0.10, 0.05 and 0.005 in., respectively. However, for referee testing and when required by product specifications, the ends of the ½-in. wide specimen shall be symmetrical within 0.01 in.

NOTE 10—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (*a*) the above tolerances are used; (*b*) an adequate number of marks are provided for determination of elongation; and (*c*) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 1 Rectangular Tension Test Specimens

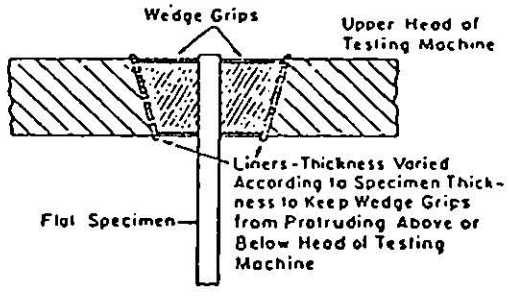
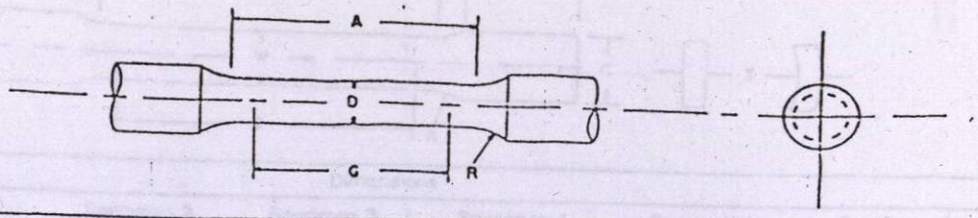



FIG. 2 Wedge Grips with Liners for Flat Specimens




| Dimensions | | | | | |
|---|---|---|---|---|---|
| | Standard Specimen | Small-Size Specimens Proportional to Standard | | | |
| | in. | in. | in. | in. | in |
| Nominal Diameter | 0.500 | 0.350 | 0.250 | 0.160 | 0.1 |
| G—Gage length | 2.000 ± 0.005 | 1.400 ± 0.005 | 1.000 ± 0.005 | 0.640 ± 0.005 | 0.450 ± |
| D—Diameter (Note 1) | 0.500 ± 0.010 | 0.350 ± 0.007 | 0.250 ± 0.005 | 0.160 ± 0.003 | 0.113 ± |
| R—Radius of fillet, min | 3/8 | 1/4 | 3/16 | 5/32 | 3/32 |
| A—Length of reduced section, min (Note 2) | 2 1/4 | 1 3/4 | 1 1/4 | 3/4 | 5/8 |

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center (c dimension).

NOTE 2—If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gage length. Reference mark measurement of elongation should, nevertheless, be spaced at the indicated gage length.

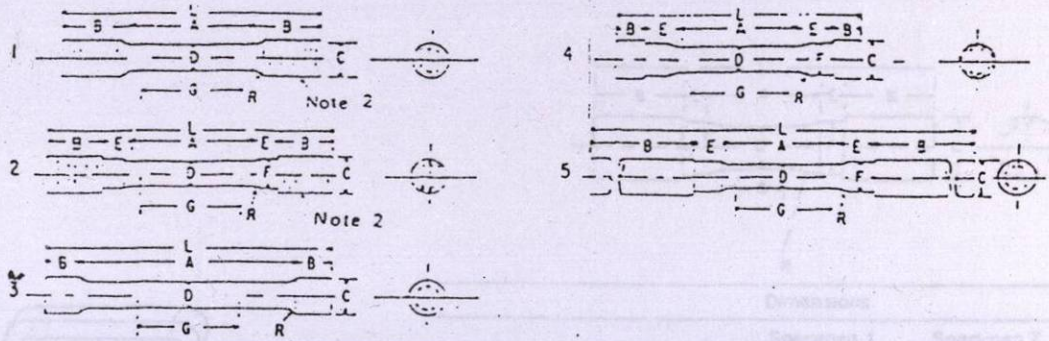
NOTE 3—The gage length and fillets may be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen t the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—On the round specimens in Figs. 8 and 9, the gage lengths are equal to four times the nominal diameter. In some product specifications other specim be provided for, but unless the 4-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the test specimen.

NOTE 5—The use of specimens smaller than 0.250-in. diameter shall be restricted to cases when the material to be tested is of insufficient size to obta specimens or when all parties agree to their use for acceptance testing. Similar specimens require suitable equipment and greater skill in both machining and te

NOTE 6—Five sizes of specimens often used have diameters of approximately 0.505, 0.357, 0.252, 0.160, and 0.113 in., the reason being to permit easy cal stress from loads, since the corresponding cross-sectional areas are equal or close to 0.200, 0.100, 0.0500, 0.0200, and 0.0100 in.², respectively. Thus, when t diameters agree with these values, the stresses (or strengths) may be computed using the simple multiplying factors 5, 10, 20, 50, and 100, respectively. T values of these five diameters do not result in correspondingly convenient cross-sectional areas and multiplying factors.

FIG. 8 Standard 0.500-in. Round Tension Test Specimen with 2-in. Gage Length and Examples of Small-Size Specimens Proportio the Standard Specimen



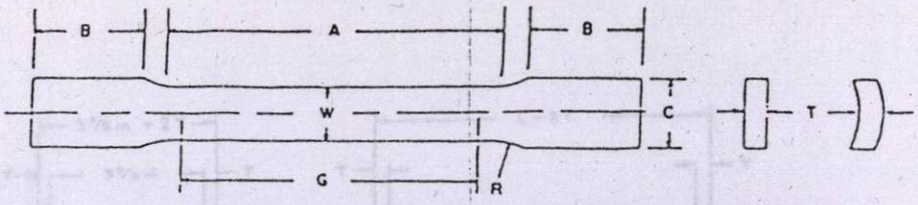

| Dimensions | | | | | |
|---|---|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 | Specimen 4 | Specimen |
| | in. | in. | in. | in. | in. |
| G—Gage length | 2.000 ± 0.005 | 2.000 ± 0.005 | 2.000 ± 0.005 | 2.000 ± 0.005 | 2.000 ± 0.0 |
| D—Diameter (Note 1) | 0.500 ± 0.010 | 0.500 ± 0.010 | 0.500 ± 0.010 | 0.500 ± 0.010 | 0.500 ± 0.0 |
| R—Radius of fillet, min | 3/8 | 3/8 | 1/16 | 3/8 | 3/8 |
| A—Length of reduced section | 2 1/4, min | 2 1/4, min | 4, approximately | 2 1/4, min | 2 1/4, min |
| L—Over-all length, approximate | 5 | 5 1/2 | 5 1/2 | 4 3/4 | 5 1/2 |
| B—Length of end section (Note 3) | 1 3/8, approximately | 1, approximately | 3/4, approximately | 1/2, approximately | 3, min |
| C—Diameter of end section | 3/4 | 3/4 | 23/32 | 7/8 | 3/4 |
| E—Length of shoulder and fillet section, approximate | ... | 3/8 | ... | 3/4 | 5/8 |
| F—Diameter of shoulder | ... | 5/8 | ... | 5/8 | 19/32 |

NOTE 1—The reduced section may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. larger in diameter than the c

NOTE 2—On Specimens 1 and 2, any standard thread is permissible that provides for proper alignment and aids in assuring that the specimen will break wit reduced section.

NOTE 3—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distanc to two thirds or more of the length of the grips.

FIG. 9 Various Types of Ends for Standard Round Tension Test Specimens




| | Dimensions | | | | | | |
|---|---|---|---|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 | Specimen 4 | Specimen 5 | Specimen 6 | Specimen 7 |
| | in. | in. | in. | in. | in. | in. | in. |
| G—Gage length | 2.000 ± 0.005 | 2.000 ± 0.005 | 8.00 ± 0.01 | 2.000 ± 0.005 | 4.000 ± 0.005 | 2.000 ± 0.005 | 4.000 ± 0.005 |
| W—Width (Note 1) | 0.500 ± 0.010 | 1½ + ⅛, −¼ | 1½ + ⅛, −¼ | 0.750 ± 0.031 | 0.750 ± 0.031 | 1.000 ± 0.062 | 1.000 ± 0.062 |
| T—Thickness | measured thickness of specimen | | | | | | |
| R—Radius of fillet, min | ½ | 1 | 1 | 1 | 1 | 1 | 1 |
| A—Length of reduced section, min | 2¼ | 2¼ | 9 | 2¼ | 4½ | ¼ | 4½ |
| B—Length of grip section, min (Note 2) | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| C—Width of grip section, approximate (Note 3) | 1 1/16 | 2 | 2 | 1 | 1 | 1½ | 1½ |

NOTE 1—The ends of the reduced section shall differ in width by not more than 0.002 in. for specimen 1, and 4, and not more than 0.005 in. for specimens 2, 3, 5, 6, and 7. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 0.005 in. greater than the width at the center for 2-in. gage length specimens, not more than 0.008 in. greater than the width at the center for 4-in. gage length specimens, and not more than 0.015 in. greater than the width at the center for 8-in. gage length specimens.

NOTE 2—It is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 3—The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.05 in. for specimens 1, 4, and 5, and 0.10 in. for specimens 2, 3, and 7.

NOTE 4—For circular segments, the cross-sectional area may be calculated by multiplying W and T. If the ratio of the dimension W to the diameter of the tubular section is more than about ¼, the error using this method to calculate the cross-sectional area may be appreciable and it may be desirable to use a more exact method in determining the area.

NOTE 5—Specimens with G/W less than 4 should not be used for determination of elongation.

NOTE 6—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided the [illegible] is used. If an extensometer is used, a set of marks are provided for determination of elongation; and for when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2W from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 13 Tension Test Specimens for Large-Diameter Tubular Products

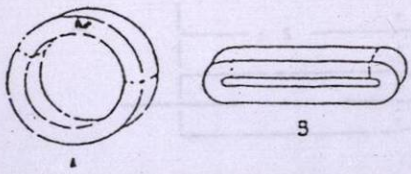
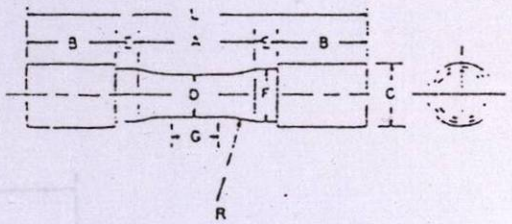



FIG. 14 Location of Transverse Tension Test Specimen in Ring Cut from Tubular Products




| | Dimensions | | |
|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 |
| | in. | in. | in. |
| G—Length of parallel section | Shall be equal to or greater than diameter D | | |
| D—Diameter | 0.500 ± 0.010 | 0.750 ± 0.015 | 1.25 ± 0.02 |
| R—Radius of fillet, min | 1 | 1 | 2 |
| A—Length of reduced section, min | 1¼ | 1½ | 2¼ |
| L—Over-all length, min | 3¾ | 4 | 6⅜ |
| B—Length of end section, approximate | 1 | 1 | 1¾ |
| C—Diameter of end section, approximate | ¾ | 1⅛ | 1⅞ |
| E—Length of shoulder, min | ¼ | ¼ | 5/16 |
| F—Diameter of shoulder | ⅜ ± 1/64 | 15/16 ± 1/64 | 1 7/16 ± 1/64 |

NOTE—The reduced section and shoulders (dimensions A, D, E, F, G, and R) shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load can be axial. Commonly the ends are threaded and have the dimensions B and C given above.

FIG. 15 Standard Tension Test Specimen for Cast Iron

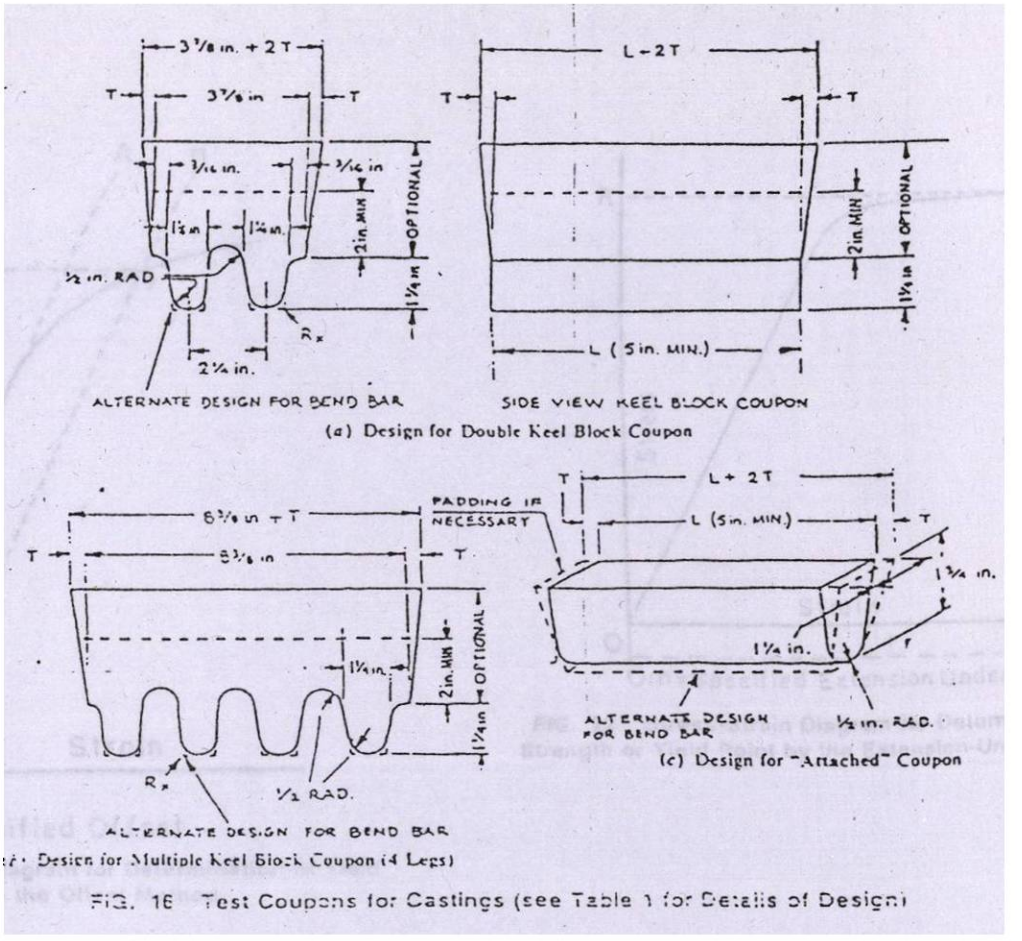
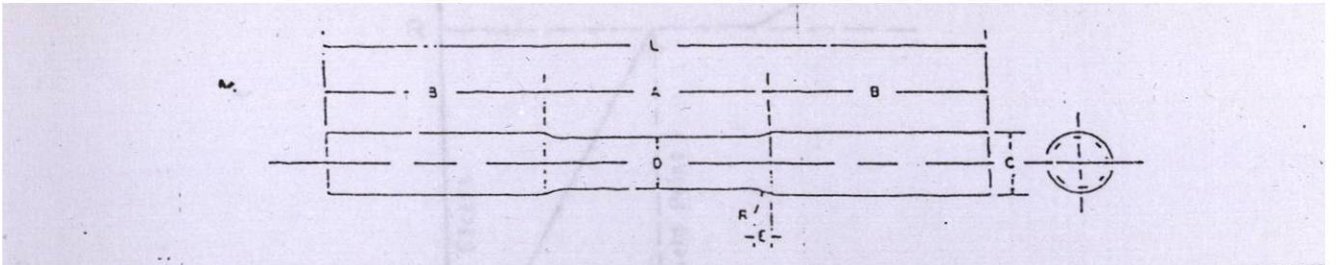



FIG. 16 Test Coupons for Castings (see Table 1 for Details of Design)




| Dimensions | in. |
|---|---|
| *D*—Diameter | ⅝ |
| *R*—Radius of fillet | 5/16 |
| *A*—Length of reduced section | 2½ |
| *L*—Over-all length | 7½ |
| *B*—Length of end section | 2½ |
| *C*—Diameter of end section | ¾ |
| *E*—Length of fillet | 3/16 |

**FIG. 17 Standard Tension Test Specimen for Malleable Iron**

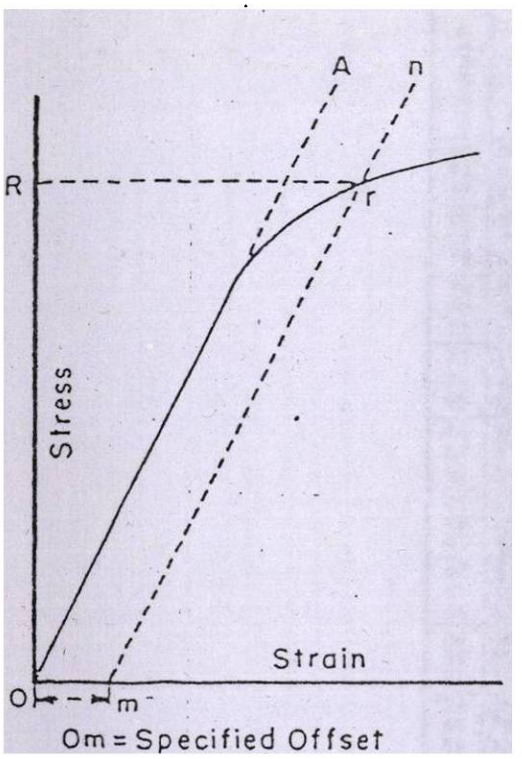



FIG. 21 *Stress-Strain Diagram for Determination of Yield* Strength by the Offset Method

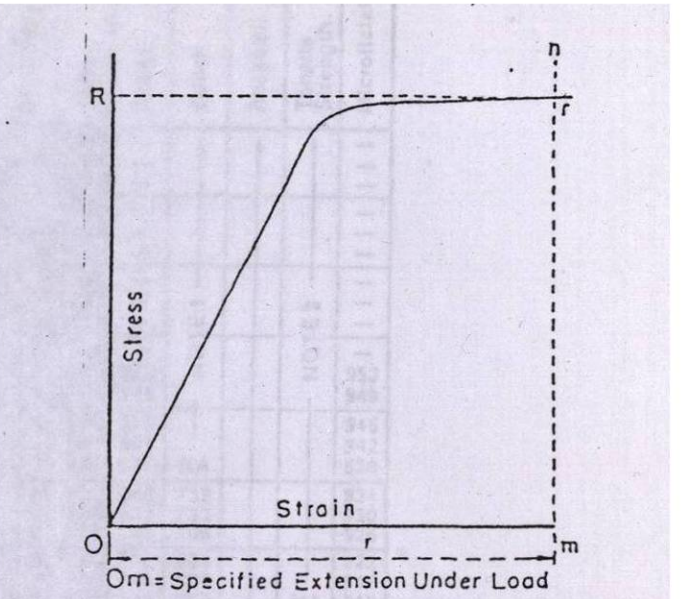



FIG. 22 Stress-Strain Diagram for Determination of Yield Strength or Yield Point by the Extension-Under-Load Method

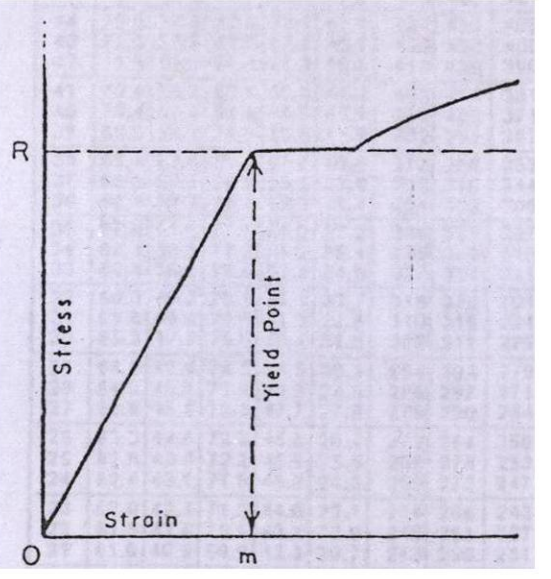



FIG. 23 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee

## Hardened steel and hard alloys

| C | A | D | 15-N | 30-N | 45-N | HV | HK | HB | G | KSI | WMN |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 kg *Brale* | 60 kg *Brale* | 100 kg *Brale* | 15 kg N *Brale* | 30 kg N *Brale* | 45 kg N *Brale* | Vickers 10 kg | 500 gm & over | 3000 kg. 10mm ball | 150 kg 1/16" ball | 1000 lbs/sq. in. | 1000 gm |
| Rockwell | Rockwell | Rockwell | Superficial | Superficial | Superficial | Vickers | Knoop | Brinell | Rockwell | Tensile Strength | Microfical |
| 80 | 92.0 | 86.5 | 96.5 | 92.0 | 87.0 | 1865 | | | | | |
| 79 | 91.5 | 85.5 | 96.3 | 91.5 | 86.5 | 1787 | | | | | |
| 78 | 91.0 | 84.5 | 96.0 | 91.0 | 85.5 | 1710 | | | | | |
| 77 | 90.5 | 84.0 | 95.8 | 90.5 | 84.5 | 1633 | | | | | |
| 76 | 90.0 | 83.0 | 95.5 | 90.0 | 83.5 | 1556 | | | | | |
| 75 | 89.5 | 82.5 | 95.3 | 89.0 | 82.5 | 1478 | | | | | |
| 74 | 89.0 | 81.5 | 95.0 | 88.5 | 81.5 | 1400 | | | | | |
| 73 | 88.5 | 81.0 | 94.8 | 88.0 | 80.5 | 1323 | | | | | |
| 72 | 88.0 | 80.0 | 94.5 | 87.0 | 79.5 | 1245 | | | | | |
| 71 | 87.0 | 79.5 | 94.3 | 86.5 | 78.5 | 1160 | | NOTE 1 | | NOTE 2 | |
| 70 | 86.5 | 78.5 | 94.0 | 86.0 | 77.5 | 1076 | 972 | | | | 953 |
| 69 | 86.0 | 78.0 | 93.5 | 85.0 | 76.5 | 1004 | 946 | | | | 949 |
| 68 | 85.6 | 76.9 | 93.2 | 84.4 | 75.4 | 940 | 920 | | | | 945 |
| 67 | 85.0 | 76.1 | 92.9 | 83.6 | 74.2 | 900 | 895 | | | | 942 |
| 66 | 84.5 | 75.4 | 92.5 | 82.8 | 73.3 | 865 | 870 | NA | | | 938 |
| 65 | 83.9 | 74.5 | 92.2 | 81.9 | 72.0 | 832 | 846 | 739 | | | 934 |
| 64 | 83.4 | 73.8 | 91.8 | 81.1 | 71.0 | 800 | 822 | 722 | | | 930 |
| 63 | 82.8 | 73.0 | 91.4 | 80.1 | 69.9 | 772 | 799 | 706 | | | 926 |
| 62 | 82.3 | 72.2 | 91.1 | 79.3 | 68.8 | 746 | 776 | 688 | | | 922 |
| 61 | 81.8 | 71.5 | 90.7 | 78.4 | 67.7 | 720 | 754 | 670 | | | 917 |
| 60 | 81.2 | 70.7 | 90.2 | 77.5 | 66.6 | 697 | 732 | 654 | | NA | 913 |
| 59 | 80.7 | 69.9 | 89.8 | 76.6 | 65.5 | 674 | 710 | 634 | | 351 | 909 |
| 58 | 80.1 | 69.2 | 89.3 | 75.7 | 64.3 | 653 | 690 | 615 | | 338 | 904 |
| 57 | 79.6 | 68.5 | 88.9 | 74.8 | 63.2 | 633 | 670 | 595 | | 325 | 900 |
| 56 | 79.0 | 67.7 | 88.3 | 73.9 | 62.0 | 613 | 650 | 577 | | 313 | 896 |
| 55 | 78.5 | 66.9 | 87.9 | 73.0 | 60.9 | 595 | 630 | 560 | | 301 | 891 |
| 54 | 78.0 | 66.1 | 87.4 | 72.0 | 59.8 | 577 | 612 | 543 | | 292 | 887 |
| 53 | 77.4 | 65.4 | 86.9 | 71.2 | 58.6 | 560 | 594 | 525 | | 283 | 883 |
| 52 | 76.8 | 64.6 | 86.4 | 70.2 | 57.4 | 544 | 576 | 512 | | 273 | 879 |
| 51 | 76.3 | 63.8 | 85.9 | 69.4 | 56.1 | 528 | 558 | 496 | | 264 | 874 |
| 50 | 75.9 | 63.1 | 85.5 | 68.5 | 55.0 | 513 | 542 | 481 | | 255 | 870 |
| 49 | 75.2 | 62.1 | 85.0 | 67.6 | 53.8 | 498 | 526 | 469 | | 246 | 865 |
| 48 | 74.7 | 61.4 | 84.5 | 66.7 | 52.5 | 484 | 510 | 455 | | 238 | 861 |
| 47 | 74.1 | 60.8 | 83.9 | 65.8 | 51.4 | 471 | 495 | 443 | | 229 | 856 |
| 46 | 73.6 | 60.0 | 83.5 | 64.8 | 50.3 | 458 | 480 | 432 | | 221 | 851 |
| 45 | 73.1 | 59.2 | 83.0 | 64.0 | 49.0 | 446 | 466 | 421 | | 215 | 847 |
| 44 | 72.5 | 58.5 | 82.5 | 63.1 | 47.8 | 434 | 452 | 409 | | 208 | 842 |
| 43 | 72.0 | 57.7 | 82.0 | 62.2 | 46.7 | 423 | 438 | 400 | | 201 | 837 |
| 42 | 71.5 | 56.9 | 81.5 | 61.3 | 45.5 | 412 | 426 | 390 | | 194 | 832 |
| 41 | 70.9 | 56.2 | 80.9 | 60.4 | 44.3 | 402 | 414 | 381 | | 188 | 827 |
| 40 | 70.4 | 55.4 | 80.4 | 59.5 | 43.1 | 392 | 402 | 371 | | 182 | 822 |
| 39 | 69.9 | 54.6 | 79.9 | 58.5 | 41.9 | 382 | 391 | 362 | | 177 | 817 |
| 38 | 69.4 | 53.8 | 79.4 | 57.7 | 40.8 | 372 | 380 | 353 | | 171 | 812 |
| 37 | 68.9 | 53.1 | 78.8 | 56.8 | 39.6 | 363 | 370 | 344 | | 166 | 807 |
| 36 | 68.4 | 52.3 | 78.3 | 55.9 | 38.4 | 354 | 360 | 336 | | 161 | 802 |
| 35 | 67.9 | 51.5 | 77.7 | 55.0 | 37.2 | 345 | 351 | 327 | | 156 | 798 |
| 34 | 67.4 | 50.8 | 77.2 | 54.2 | 36.1 | 336 | 342 | 319 | | 152 | 793 |
| 33 | 66.8 | 50.0 | 76.6 | 53.3 | 34.9 | 327 | 334 | 311 | | 149 | 788 |
| 32 | 66.3 | 49.2 | 76.1 | 52.1 | 33.7 | 318 | 326 | 301 | | 146 | 783 |
| 31 | 65.8 | 48.4 | 75.6 | 51.3 | 32.5 | 310 | 318 | 294 | NA | 141 | 778 |
| 30 | 65.3 | 47.7 | 75.0 | 50.4 | 31.3 | 302 | 311 | 286 | 92.0 | 138 | 773 |
| 29 | 64.6 | 47.0 | 74.5 | 49.5 | 30.1 | 294 | 304 | 279 | 91.0 | 135 | 768 |
| 28 | 64.3 | 46.1 | 73.9 | 48.6 | 28.9 | 286 | 297 | 271 | 90.0 | 131 | 762 |
| 27 | 63.8 | 45.2 | 73.3 | 47.7 | 27.8 | 279 | 290 | 264 | 89.0 | 128 | 757 |
| 26 | 63.3 | 44.6 | 72.8 | 46.8 | 26.7 | 272 | 284 | 258 | 88.0 | 125 | 751 |
| 25 | 62.8 | 43.8 | 72.2 | 45.9 | 25.5 | 266 | 278 | 253 | 87.0 | 123 | 746 |
| 24 | 62.4 | 43.1 | 71.6 | 45.0 | 24.3 | 260 | 272 | 247 | 86.0 | 119 | 741 |
| 23 | 62.0 | 42.1 | 71.0 | 44.0 | 23.1 | 254 | 266 | 243 | 84.5 | 117 | 736 |
| 22 | 61.5 | 41.6 | 70.5 | 43.2 | 22.0 | 248 | 261 | 237 | 83.5 | 115 | 730 |
| 21 | 61.0 | 40.9 | 69.9 | 42.3 | 20.7 | 243 | 256 | 231 | 82.5 | 112 | 725 |
| 20 | 60.5 | 40.1 | 69.4 | 41.5 | 19.6 | 238 | 251 | 226 | 81.0 | 110 | 720 |

Although conversion tables dealing with hardness can only be approximate, it is of considerable value to be able to compare different hardness scales. This table is based on the assumption that the metal tested is homogeneous to a depth several times as great as the depth of the indentation.

The indentation hardness values measured on the various scales depend on the work hardening behavior of the material during the test, and this in turn depends on the degree of previous cold working of the material. The B-scale relationships in the table are based largely on annealed metals for the low values and cold worked metals for the higher values. Therefore, annealed metals of high B-scale

## Soft steel, grey and malleable cast iron and most non-ferrous metals

| B 1/16" ball | F 60 kg 1/16" ball | G 150 kg 1/16" ball | 15-T 15 kg 1/16" ball | 30-T 30 kg 1/16" ball | 45-T 45 kg 1/16" ball | E 100 kg 1/8" ball | H 60 kg 1/8" ball | K 150 kg 1/8" ball | A 60 kg Brale | HK 500 gm & over | HB 500 kg 10mm ball | HB 3000 kg 10 kg HV | KSI 1000 lbs/sq. in. | WMN 1000 gm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rockwell | Rockwell | Rockwell | Superficial | Superficial | Superficial | Rockwell | Rockwell | Rockwell | Rockwell | Knoop | Brinell | Brinell 10mm Vickers 136° | Tensile Strength | Microficial |
| | | 82.5 | 93.1 | 83.1 | 72.9 | | | | 61.5 | 251 | 201 | 240 | 116 | 730 |
| | | 81.0 | 92.8 | 82.5 | 71.9 | | | | 60.9 | 246 | 195 | 234 | 114 | 725 |
| | | 79.0 | 92.5 | 81.8 | 70.9 | | | | 60.2 | 241 | 189 | 228 | 109 | 719 |
| | | 77.5 | 92.1 | 81.1 | 69.9 | | | | 59.5 | 236 | 184 | 222 | 104 | 713 |
| | | 76.0 | 91.8 | 80.4 | 68.9 | | | | 58.9 | 231 | 179 | 216 | 102 | 707 |
| | | 74.0 | 91.5 | 79.8 | 67.9 | | | | 58.3 | 226 | 175 | 210 | 100 | 701 |
| | | 72.5 | 91.2 | 79.1 | 66.9 | | | | 57.6 | 221 | 171 | 205 | 98 | 696 |
| | | 71.0 | 90.8 | 78.4 | 65.9 | | | NA | 57.0 | 216 | 167 | 200 | 94 | 690 |
| | | 69.0 | 90.5 | 77.8 | 64.8 | | | 100 | 56.4 | 211 | 163 | 195 | 92 | 684 |
| | | 67.5 | 90.2 | 77.1 | 63.8 | | | | 99.5 | 55.8 | 206 | 160 | 90 | 679 |
| | | 66.0 | 89.9 | 76.4 | 62.8 | | | | 98.5 | 55.2 | 201 | 157 | 89 | 674 |
| | | 64.0 | 89.5 | 75.8 | 61.8 | | | | 98.0 | 54.6 | 196 | 154 | 88 | 668 |
| | | 62.5 | 89.2 | 75.1 | 60.8 | | | | 97.0 | 54.0 | 192 | 151 | 86 | 662 |
| | | 61.0 | 88.9 | 74.4 | 59.8 | | | | 96.5 | 53.4 | 188 | 148 | 84 | 656 |
| | | 59.0 | 88.6 | 73.8 | 58.8 | | | | 95.5 | 52.8 | 184 | 145 | 83 | 651 |
| | | 57.5 | 88.2 | 73.1 | 57.8 | | | | 94.5 | 52.3 | 180 | 142 | 82 | 646 |
| | | 56.0 | 87.9 | 72.4 | 56.8 | | | | 94.0 | 51.7 | 176 | 140 | 81 | 640 |
| | | 54.0 | 87.6 | 71.8 | 55.8 | | | | 93.0 | 51.1 | 173 | 137 | 80 | 634 |
| | | 52.5 | 87.3 | 71.1 | 54.8 | | | | 92.0 | 50.6 | 170 | 135 | 77 | 629 |
| | | 51.0 | 86.9 | 70.4 | 53.8 | | | | 91.0 | 50.0 | 167 | 133 | 73 | 624 |
| | | 49.0 | 86.6 | 69.7 | 52.8 | | | | 90.5 | 49.5 | 164 | 130 | 72 | 618 |
| | | 47.5 | 86.3 | 69.1 | 51.8 | | | | 89.5 | 48.9 | 161 | 128 | 70 | 612 |
| | | 46.0 | 86.0 | 68.4 | 50.8 | | | | 88.5 | 48.4 | 158 | 126 | 69 | 607 |
| | | 44.0 | 85.6 | 67.7 | 49.8 | | | | 88.0 | 47.9 | 155 | 124 | 68 | 602 |
| | NA | 42.5 | 85.3 | 67.1 | 48.8 | | | | 87.0 | 47.3 | 152 | 122 | 67 | 596 |
| | 99.6 | 41.0 | 85.0 | 66.4 | 47.8 | | | | 86.0 | 46.8 | 150 | 120 | 66 | 592 |
| | 99.1 | 39.0 | 84.7 | 65.7 | 46.8 | | | | 85.0 | 46.3 | 147 | 118 | 65 | 587 |
| | 98.5 | 37.5 | 84.3 | 65.1 | 45.8 | | | | 84.5 | 45.8 | 145 | 116 | 64 | 581 |
| | 98.0 | 36.0 | 84.0 | 64.4 | 44.8 | NA | | | 83.5 | 45.3 | 143 | 114 | 63 | 576 |
| | 97.4 | 34.5 | 83.7 | 63.7 | 43.8 | 100 | | | 82.5 | 44.8 | 141 | 112 | 62 | 571 |
| | 96.8 | 32.5 | 83.4 | 63.1 | 42.8 | 99.5 | | | 81.5 | 44.3 | 139 | 110 | 61 | 566 |
| | 96.2 | 31.0 | 83.0 | 62.4 | 41.8 | 99.0 | | | 81.0 | 43.8 | 137 | 109 | 60 | 561 |
| | 95.6 | 29.5 | 82.7 | 61.7 | 40.8 | 98.0 | | | 80.0 | 43.3 | 135 | 107 | 59 | 556 |
| | 95.1 | 28.0 | 82.4 | 61.0 | 39.8 | 97.5 | | | 79.0 | 42.8 | 133 | 106 | 58 | 551 |
| | 94.5 | 26.5 | 82.1 | 60.4 | 38.7 | 97.0 | | | 78.0 | 42.3 | 131 | 104 | 57 | 546 |
| | 93.9 | 25.0 | 81.8 | 59.7 | 37.7 | 96.0 | | | 77.5 | 41.8 | 129 | 102 | 56 | 542 |
| | 93.4 | 23.5 | 81.4 | 59.0 | 36.7 | 95.5 | | | 76.5 | 41.4 | 127 | 101 | NA | 537 |
| | 92.8 | 22.0 | 81.1 | 58.4 | 35.7 | 95.0 | | | 75.5 | 40.9 | 125 | 99 | | 532 |
| | 92.2 | 20.5 | 80.8 | 57.7 | 34.7 | 94.5 | | | 74.5 | 40.4 | 124 | 98 | | 527 |
| | 91.7 | 19.0 | 80.5 | 57.0 | 33.7 | 93.5 | | | 74.0 | 40.0 | 122 | 96 | | 522 |
| | 91.1 | 17.5 | 80.1 | 56.4 | 32.7 | 93.0 | | | 73.0 | 39.5 | 120 | 95 | | 517 |
| | 90.5 | 16.0 | 79.8 | 55.7 | 31.7 | 92.5 | | | 72.0 | 39.0 | 118 | 94 | | 512 |
| | 90.0 | 14.5 | 79.5 | 55.0 | 30.7 | 92.0 | | | 71.0 | 38.6 | 117 | 92 | | 507 |
| | 89.4 | 13.0 | 79.2 | 54.4 | 29.7 | 91.0 | | | 70.5 | 38.1 | 115 | 91 | | 502 |
| | 88.8 | 11.5 | 78.8 | 53.7 | 28.7 | 90.5 | | | 69.5 | 37.7 | 114 | 90 | | 497 |
| | 88.2 | 10.0 | 78.5 | 53.0 | 27.7 | 90.0 | | | 68.5 | 37.2 | 112 | 89 | | 492 |
| | 87.7 | 8.5 | 78.2 | 52.4 | 26.7 | 89.5 | | | 68.0 | 36.8 | 111 | 87 | | 487 |
| | 87.1 | 7.0 | 77.9 | 51.7 | 25.7 | 89.0 | | | 67.0 | 36.3 | 110 | 86 | | 482 |
| | 86.5 | 5.5 | 77.5 | 51.0 | 24.7 | 88.0 | | | 66.0 | 35.9 | 109 | 85 | | 477 |
| | 86.0 | 4.0 | 77.2 | 50.3 | 23.7 | 87.5 | | | 65.0 | 35.5 | 108 | 84 | | 472 |
| | 85.4 | 2.5 | 76.9 | 49.7 | 22.7 | 87.0 | | | 64.5 | 35.0 | 107 | 83 | | 468 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 84.8 | NA | 76.6 | 49.0 | 21.7 | 86.5 | | | 63.5 | 34.6 | 106 | 82 | | |
| | 84.3 | | 76.2 | 48.3 | 20.7 | 85.5 | | | 62.5 | 34.1 | 105 | 81 | | |
| | 83.7 | | 75.9 | 47.7 | 19.7 | 85.0 | | | 61.5 | 33.7 | 104 | 80 | | |
| | 83.1 | | 75.6 | 47.0 | 18.7 | 84.5 | | | 61.0 | 33.3 | 103 | 80 | | |
| | 82.6 | | 75.3 | 46.3 | 17.7 | 84.0 | | | 60.0 | 32.9 | 102 | 79 | | |
| | 82.0 | | 74.9 | 45.7 | 16.7 | 83.5 | | | 59.0 | 32.4 | 101 | 78 | | |
| | 81.4 | | 74.6 | 45.0 | 15.7 | 82.5 | | | 58.0 | 32.0 | 100 | 77 | | |
| | 80.8 | | 74.3 | 44.3 | 14.7 | 82.0 | | | 57.5 | 31.6 | 99 | 76 | | |
| | 80.3 | | 74.0 | 43.7 | 13.6 | 81.5 | | | 56.5 | 31.2 | 98 | 75 | | |
| | 79.7 | | 73.6 | 43.0 | 12.6 | 81.0 | | | 55.5 | 30.7 | 97 | 75 | | |
| | 79.1 | | 73.3 | 42.3 | 11.6 | 80.0 | | | 54.5 | 30.3 | 96 | 74 | | |
| | 78.6 | | 73.0 | 41.6 | 10.6 | 79.5 | | | 54.0 | 29.9 | 95 | 73 | | |
| | 78.0 | | 72.7 | 41.0 | 9.6 | 79.0 | NA | | 53.0 | 29.5 | 94 | 72 | | |
| | 77.4 | | 72.3 | 40.3 | 8.6 | 78.5 | 100 | | 52.0 | 29.1 | 93 | 72 | | |
| | 76.9 | | 72.0 | 39.6 | 7.6 | 78.0 | 99.5 | | 51.5 | 28.7 | 92 | 71 | | |
| | 76.3 | | 71.7 | 39.0 | 6.6 | 77.0 | 99.0 | | 50.5 | 28.2 | 91 | 70 | | |
| | 75.7 | | 71.4 | 38.3 | 5.6 | 76.5 | 98.8 | | 49.5 | 27.8 | 90 | 69 | | |
| | 75.2 | | 71.0 | 37.6 | 4.6 | 76.0 | 98.5 | | 48.5 | 27.4 | 89 | 69 | | |
| | 74.6 | | 70.7 | 37.0 | 3.6 | 75.5 | 98.0 | | 48.0 | 27.0 | 88 | 68 | | |
| | 74.0 | | 70.4 | 36.3 | 2.6 | 75.0 | 97.8 | | 47.0 | 26.6 | 87 | 67 | | |
| | 73.5 | | 70.0 | 35.6 | 1.0 | 74.0 | 97.5 | | 46.0 | 26.0 | 87 | 66 | | |
| | 73.0 | | 69.3 | 34.5 | NA | 73.5 | 97.0 | | 45.0 | 25.5 | 86 | 66 | | |
| | 72.5 | | 69.5 | 34.0 | | 73.0 | 96.5 | | 44.5 | 25.0 | 85 | 65 | | |
| | 72.0 | | 69.0 | 33.0 | | 72.5 | 96.3 | | 43.5 | 24.5 | 84 | 65 | | |
| | 71.0 | | 68.8 | 32.5 | | 72.0 | 96.0 | | 42.5 | 24.3 | 83 | 64 | | |
| | 70.5 | | 68.5 | 32.0 | | 71.0 | 95.5 | | 41.5 | 24.0 | 82 | 64 | | |
| | 70.0 | | 68.0 | 31.0 | | 70.5 | 95.3 | | 41.0 | 23.5 | 82 | 63 | | |
| | 69.5 | | 67.8 | 30.5 | | 70.0 | 95.0 | | 40.0 | 23.0 | 81 | 62 | | |
| | 69.0 | | 67.5 | 29.5 | | 69.5 | 94.5 | | 39.0 | 22.5 | 81 | 62 | | |
| | 68.5 | | 67.3 | 29.0 | | 68.5 | 94.3 | | 38.0 | 22.0 | 80 | 61 | | |
| | 68.0 | | 67.0 | 28.5 | | 68.0 | 94.0 | | 37.5 | 21.5 | 79 | 61 | | |
| | 67.0 | | 66.5 | 27.5 | | 67.5 | 93.5 | | 36.5 | 21.3 | 78 | 60 | | |
| | 66.5 | | 66.3 | 27.0 | | 67.0 | 93.0 | | 35.5 | 21.0 | 78 | 60 | | |
| | 66.0 | | 66.0 | 26.0 | | 66.5 | 92.8 | | 35.0 | 20.5 | 77 | 59 | | |
| | 65.5 | | 65.5 | 25.5 | | 65.5 | 92.5 | | 34.0 | 20.0 | 76 | 59 | | |
| | 65.0 | | 65.3 | 25.0 | | 65.0 | 92.0 | | 33.0 | NA | 75 | 59 | | |
| | 64.5 | | 65.0 | 24.0 | | 64.5 | 91.8 | | 32.0 | | 75 | 58 | | |
| | 64.0 | | 64.5 | 23.5 | | 64.0 | 91.5 | | 31.5 | | 74 | 58 | | |
| | 63.5 | | 64.3 | 23.0 | | 63.5 | 91.0 | | 30.5 | | 73 | 57 | | |
| | 63.0 | | 64.0 | 22.0 | | 62.5 | 90.5 | | 29.5 | | 72 | 57 | | |
| | 62.0 | | 63.8 | 21.5 | | 62.0 | 90.3 | | 29.0 | | 71 | 57 | | |
| | 61.5 | | 63.5 | 20.5 | | 61.5 | 90.0 | | 28.0 | | 71 | 56 | | |
| | 61.0 | | 63.0 | 20.0 | | 61.0 | 89.5 | | 27.0 | | 70 | 56 | | |
| | 60.5 | | 62.8 | 19.5 | | 60.5 | 89.3 | | 26.0 | | 69 | 55 | | |
| | 60.0 | | 62.5 | 18.5 | | 60.0 | 89.0 | | 25.5 | | 69 | 55 | | |
| | 59.5 | | 62.0 | 18.0 | | 59.0 | 88.5 | | 24.5 | | 69 | 55 | | |
| | 59.0 | | 61.8 | 17.0 | | 58.5 | 88.0 | | 23.5 | | 68 | 54 | | |
| | 58.0 | | 61.5 | 16.5 | | 58.0 | 87.8 | | 23.0 | | 68 | 54 | | |
| | 57.5 | | 61.0 | 16.0 | | 57.5 | 87.5 | | 22.0 | | 63 | 54 | | |
| | 57.0 | | 60.5 | 15.0 | | 57.0 | 87.0 | | 21.0 | | 67 | 53 | | |

high nickel alloys do not conform closely to these general tables. Neither do cold-worked metals of low B-scale hardness such as aluminum and the softer alloys. Special correlations are needed for more exact relationships in these cases. All values are consistent with ASTM E-140 Tables 1 and 2, and ASTM A-370 Tables 3A and 3B, where applicable. Microficial number values were developed in the *Wilson* Standards Laboratory.

Note 1: A 10mm steel ball is used for 450 BHN and below. A 10mm carbide ball is used above 450 BHN.

Note 2: The tensile strength relation to hardness is inexact, even for steel, unless it is determined for a specific material.